VAN NOSTRAND'S

ENGINEERING MAGAZINE.

NO. CLXXXII.—FEBRUARY, 1884.—VOL. XXX.

SOME EXPERIMENTS UPON THE "OTTO" GAS ENGINE.*

By MORGAN BROOKS and J. E. STEWARD, Stevens Institute of Technology, 1883.

INTRODUCTION BY PROF. R. H. THURSTON.

Contributed to Van Nostrand's Engineering Magazine.

Introduction.

The following report on the trials of the Otto Gas Engine, by Messrs. Brooks and Steward, embodies a very careful examination, both theoretically and experimentally, of the performance of that form of motor, made with a view to determine, not only the actual efficiency and economy of the machine, but also the extent and the proportions of the losses met with in its ordinary operation. Some earlier investigations had been directed into this line of research, and a fairly good idea had been obtained of the causes of waste in the gas-engine. It seemed to the writer, however, that the collection of other data bearing upon this subject was desirable, and he had already obtained some figures from experimental work that were instructive and interesting. Among the latter may be mentioned a series of results obtained during the investigations, made under his direction, and which included trials of the Otto engine as well as other forms of gas-engine, in which the distribution of heat in useful and lost forms of energy was determined with care.

In these cases, the consumption of water-gas varied from 21.2 to 23.4 cubic feet per hour and per horse-power in engines of 6 or 7 indicated horse-power, up to 23.5 to 24.5 with engines of two horse-power or less. The friction of mechanism ranged from 4 to 5 per cent of the total energy of combustion, and from 40 % power, in the smaller to 20 per cent in the larger engines; the waste at the exhaust was from 12 per cent of the total heat of combustion, in the small to 24 per cent in the large engines, and from 100 to 200 per cent of that transformed into useful work.

The water-jacket carried off from 45 to 55 per cent. of all the heat supplied by the combustion of the gas. For example: the distribution of the heat of combustion, in one case worked for the writer by his senior assistant, Mr. Cartwright, was as below:

Useful dynamometric work..	14.27
Work of the pump.....	0.42
Friction of mechanism.....	4.10
Lost in exhaust.....	23.55
Ditto in water-jacket.....	46.90
Radiation, &c.....	10.76
Total heat supplied....	100.00

* We take pleasure in acknowledging our obligations to Mr. A. W. Schleicher, of Schleicher, Schumm & Co., Philadelphia, for the use of the ten horse-power engine, supplied at the request of Prof. Thurston, for our work, and upon the performance of which our results are based. We are similarly indebted to the American Meter Co., of New York City, for the loan of standard meters used during the tests.—M. B. and J. E. S.

This engine developed seven horse-power at the brake, and indicated 8.9 H. P., consuming 21.2 or 27.6 cubic feet of gas, accordingly as the indicated or the dynamometric horse-power was made the basis of the calculation.

It seemed to the writer desirable that this method of investigation should be further developed, and that a comparison of the actual with the thermodynamic performance of the gas engine should be made, systematically determining all the data needed to make such a comparison complete, and as nearly exact as possible. This work was undertaken by Messrs. Brooks and Steward. These gentlemen had already had sufficient experience, and had shown themselves sufficiently skillful, in work of this character to insure exact results. They were given every facility that the Stevens Institute of Technology could furnish, and, at the request of the writer, Messrs. Schleicher, Schumm & Co., the builders of the engine, prepared one of their 10 horse-power Otto engines for trial, and forwarded it to the writer from Philadelphia. This engine was set up at the Stevens Institute of Technology, as described in the report, and connected as shown in the plan, Fig. 1. At the request of the writer, the American Meter Co. promptly and cheerfully supplied meters, including one of unusual size for the purpose of measuring the air, as well as the gas supplied, a measurement never before undertaken, so far as the writer is informed. The Meter Co. also afforded all needed facilities for testing the meters, before and after the trials.

The results of the investigation are given with all necessary detail in the body of the report. It will be seen, as one result of the precaution taken to measure the supply of air, that the relative volumes of air and gas are found not to be precisely determinable from figures obtained without the use of an air meter. This precaution was also found to have value as permitting a correct determination of the effect of varying the supply of air and of gas independently, either with or without change of proportions. (Section 5.)

The determination of the proper proportion of air to gas is important and interesting (section 9); and the comparison of the lines of the indicator with theoretic curves is still more interesting and novel, as well as very instructive (sections 12 and 13). The fact that combustion is progressive, even into the expansion period, is probably here, for the first time, exhibited by direct investigation (section 15). The analysis of the efficiency of the engine affords a means of making a comparison of the thermodynamic with the actual efficiency of this class of heat-engine. It is seen that the total heat accounted for thermodynamically, consisting of that transformed into work and that expelled with the exhaust, amount to 34 per cent. of the total heat actually supplied, and that the other wastes, by way of the water-jacket and otherwise, amount to 66 per cent. The thermodynamic efficiency is therefore about 17-32ds, and the actual efficiency 17-100ths, or 52 and 17 per cent., respectively. It may probably be stated, as a general fact, that in gas engines having water-jackets, about twice as much gas is demanded by even good machines, as thermodynamic calculation would indicate, and it would seem equally evident that, could this loss by the jacket be evaded, the gas-engine would at once assume a vastly more important position as prime-motor than it to-day occupies. Even now, the gas-engine has found innumerable applications; and, as its economy is increased by improvements in design and construction and by the introduction, as suggested in the closing paragraph of the report, of special heating gases, costing sometimes but 50 cents per thousand feet, and bringing down the cost per day to but about $2.50, its field will indefinitely widen. Its convenience and its safety are advantages which go far also toward compensating every economical disadvantage.

ROBERT H. THURSTON.

Stevens Institute of Technology,
January, 1884.

---

1. THE ENGINE AND ACCESSORIES.

Below are the dimensions of the principal parts of the engine, and of such accessories as are involved in the calculations.*

* For complete description see U. S. Letters Patent, No. 194,473, dated October, 1877.

Stroke	14	in.	(356 mm.)
Diameter of piston	8.5	"	(216 ")
" " piston rod	1.75	"	(44 ")
" " connecting rod (crank end)	2.5	"	(63 ")
Diameter of connecting rod (piston end)	2.25	"	(57 ")
Diameter of crank shaft	4	"	(102 ")
" " fly-wheels	66	"	(1680 ")
" " brake pulley	30	"	(762 ")
Length of brake arm	16.5	"	(420 ")
Weight of both fly-wheels	1650 lbs.		(750 kilos)

Clearance (compression chamber) 38% total cylinder volume.

The ground plan (Fig. 1) shows the general arrangement of the engine, piping, and apparatus employed in making the tests.

A sixty-light dry meter was used, connected directly with the street gas main, to measure the gas used by the engine, exclusive of the igniting flames. As the engine takes gas suddenly and at intervals, it is necessary to insert a flexible rubber bag in the gas supply pipe between the meter and engine, to act as a gas reservoir, and so relieve the meter of all strain.

The supply of air was also measured. A three-hundred light meter was used for this purpose, and a pair of large rubber bags was inserted in the air pipe for a purpose similar to that of the gas bag as just described. A small fan-blower, running at about 3,000 revolutions per minute, kept these bags constantly filled with air, the pressure of which was controlled by a check valve in the pipe near the blower. A three-way cock in the air pipe under the engine (not shown in the figure) allowed the air to be taken either through the large meter or directly from the room.

The water required for the water-jacket was measured by a Crown water meter placed near the gas meter, and its temperature, both before entering and immediately after leaving the water jacket, was measured by a standard thermometer.

The three meters used were tested just before they were put in place, and an allowance has been made for the readings of the air meter, the only one appreciably inaccurate.

A Bulkley pyrometer was placed in the exhaust pipe as near as possible to the engine, giving the temperature of the discharged gases.

For the purpose of measuring the useful work of the engine a Prony brake, consisting of two iron hoops with blocks of wood fastened at short intervals, was clamped around a thirty-inch pulley on the crank shaft of the engine. A strut transmitted the pressure derived from the brake directly to a Fairbanks' platform scale. This brake worked very smoothly without use of water.

The indicator used was of the Tabor pattern. It was placed directly upon the cover of the exhaust passage, and motion was taken from the cross-head by means of a cord running about a stepped pulley to reduce the stroke.

To measure the speed of the engine a speed counter was attached to the link moving the slide valve, thus recording the number of double revolutions.

2. Summary of Tests.

The observations from which the results given in the tables were obtained, were usually made at intervals of five minutes during the tests, but oftener when any marked variation was noticed. The gas pressure was about 30 millimeters (1¼ inches) water column, and the air pressure, when the large meter and blower were used, averaged 50 millimeters (2 inches).

All results have been reduced to horse-power, as being the most convenient form for ready comparison. The "horse-power in gas burned" was calculated from the analysis of Hoboken gas, and is the dynamic equivalent of the heat capacity of the gas. The "horse-power lost by exhaust" and "by water jacket" were calculated from the specific heats of the discharged gases and of water. The indicated horse-power was computed in the ordinary way from the number of explosions and the mean effective pressure. The area of the cards between the compression and expansion lines was measured with an Amsler planimeter. An allowance was made for the area between the exhaust and admission lines, representing work done in expelling the burned gases, and in drawing in the fresh charge. This allowance is equivalent to a little more than one-tenth of an atmosphere mean effective pressure.

The figures given for gas consumed do not include the amount burned by the two igniting flames. An allowance of 7 cu. ft. (200 liters) per hour will cover this.

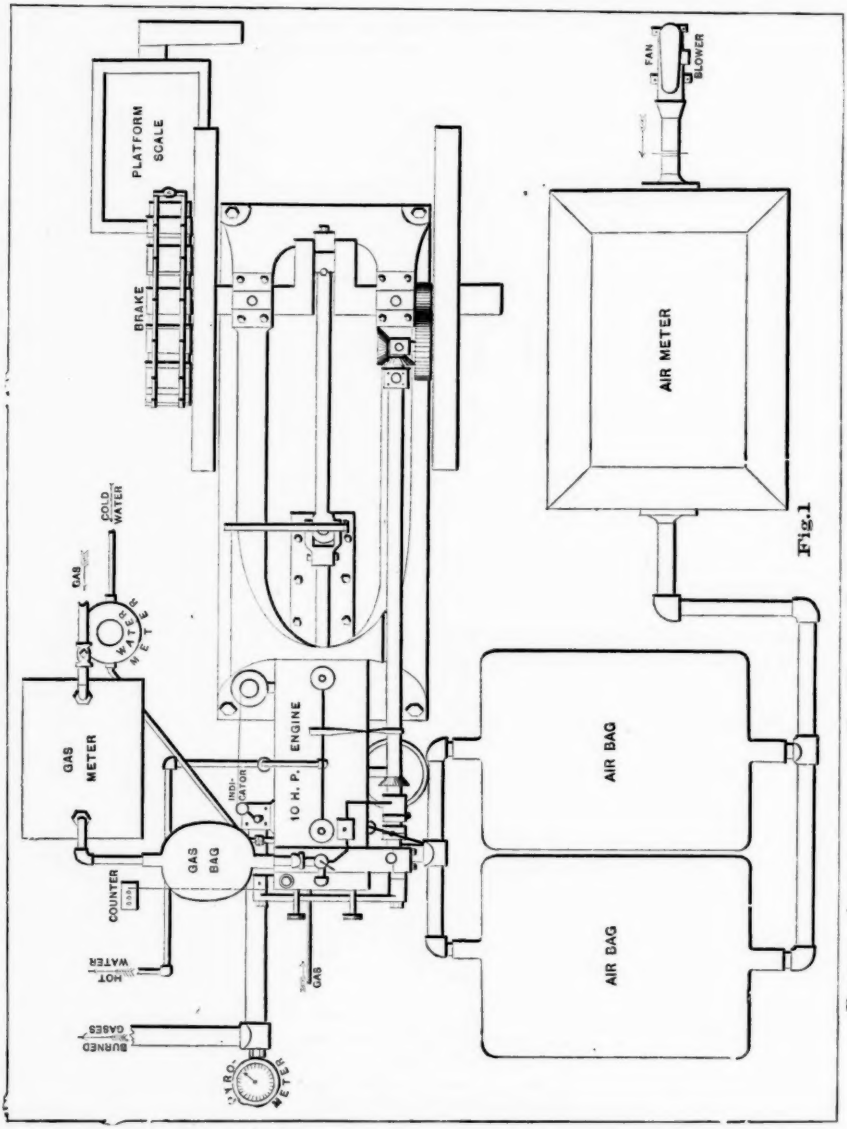


Fig. 1.

PLAN OF ARRANGEMENT FOR GAS ENGINE TRIAL.—STEVENS INSTITUTE OF TECHNOLOGY, 1883.

3. FRICTION OF ENGINE.

The difference between the indicated and the actual work gives the amount of friction in the engine. In tests 10 and 17 this falls below 15 per cent. of the indicated work, a somewhat doubtful figure. The average of all the tests at full power is 18.6 per cent friction, a remarkably good result.

4. GAS CONSUMPTION.

The consumption of gas per horse-power per hour is larger than that usu-

RESULTS OF TESTS.

	At Varying Powers.									At Full Power.										
Number of Test.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Date (1883)	5/29	5/28	5/30	5/30	5/30	6/4	6/4	6/4	5/29	5/28	6/4	6/4	6/4	6/4	6/4	6/29	6/29	6/29	6/29	6/30
Duration in minutes	15	15	30	14.5	30	10	15	10	60	30	30	30	30	30	30	30	25	20	10	30
Gas (cubic feet	12.5	17.5	63	41.5	99	28.5	46.5	34.7	249	109	115	122	105	114	115	117 5	89	72	37	105
Gas (liters	355	495	1785	1175	2805	805	1310	980	7050	3090	3255	3460	2975	3227	3255	3320	2520	2040	1050	2975
Air (cubic feet	385	—	—	—	—	277	416	283	1538	732	806	765	796	831	816	806	622	496	245	809
Air (liters	10900	—	—	—	—	7850	11800	8000	43550	20740	22850	21670	22540	23510	23040	22850	17650	14050	6940	22910
Ratio of air to gas	—	—	—	—	—	—	—	—	—	6.6	6.9	6.2	7.4	7.1	7.0	6.86	7.0	6 9	6.63	7.7
Amount of water through jacket (cubic feet	.94	4.6	4.3	4.	10.8	2.5	3.75	2.45	24.3	7.8	11.5	6.0	6.65	4.45	8.75	11.8	2.9	2.1	4.2	9.75
Amount of water through jacket (liters	26.5	131	122	113	306	71	107	69 5	690	221	325	170	188	127	248	334	82	58	116	276
Temperature of water in °C. (entering	22	22	21	21	21	22	22	22	22	22	22	22	22	22	22	23	23	23	23	24
Temperature of water in °C. (leaving	49	29	51.7	44.5	42	49.5	48	51	45.7	59.7	48	80	76	80	57	49	89.4	88.2	53	48.1
Number of double revolutions	1252	1247	2445	1184	2426	809	1212	801	4634	2100	2325	2299	2291	2461	2404	2371	1859	1472	750	2396
Number of revolutions per minute	167	166	163	163	162	162	162	160	154.5	140	155	153	153	164	160	158	149	147	150	160
Number of explosions	235	352	1224	788	1820	607	970	716	4620	Same as the number of double revolutions.										
Ratio of explosions to double revs	.19	.3	.5	.66	.75	.75	.8	.89	.997	1	1	1	1	1	1	1	1	1	1	1
Average weight on brake arm (lbs.	0	0	64	106	125	107	125	150	183	197	188	191	178	178	176	195	190	190	188	150
Average weight on brake arm (kilos.	0	0	29	48	57	49	57	68	83	89	85	87	81	81	80	88	86	86	85	68
Mean effective pressure (atmosphere)	4.2	3.3	4.4	4.3	4.1	4.	3.9	4.	4.2	4.2	4.1	4.1	3 9	3.9	3.8	4.04	3 85	3.97	4.15	3.5
Temperature of exhaust gases (°C.)	163	121	299	349	371	371	366	402	416	399	429	432	427	427	432	430	422	407	410	421
Indicated horse power	2	2.55	5.4	7.06	7.6	7 3	7 6	8.6	9.4	8 4	9.6	9.5	8.9	9.7	9.6	9.6	8.7	8.7	9.3	8.5
Effective (brake) horse power	0	0	2.73	4.5	5 3	4.5	5.4	6.3	7.6	7.2	7.8	7.8	7.1	7.7	7 5	8.1	7.4	7.2	7.4	6.3
Horse power lost by exhaust gases	2.3	—	—	—	—	6 7	6.8	7.6	7.6	6.9	7.9	7.8	7.7	8.1	8.	8.	7.3	7.	7.	7.8
Horse power lost by water jacket	6.6	8.1	11.5	16.8	19.8	18	17	18.7	35.2	25.7	26.2	30.5	31.2	22 4	26.8	26.9	20.3	17.6*	33.4*	20.6
Horse power in gas burned	12.2	17.1	30.9	42.1	48.5	41.9	45 6	51.	61.	53.4	56.4	59.8	51.5	55.9	56.4	57.6	52.3	52.9	54.4	51.5
Gas per indicated horse power per hour (cubic feet.	25	27	23.3	24.6	26	23.4	24.5	24.2	26.3	26.	24.	25.6	23.6	23 5	24 2	24.5	24 6	24.7	23.9	24.8
Gas per indicated horse power per hour (liters	708	765	660	697	736	663	694	685	745	735	680	725	668	665	685	694	697	700	677	703
Gas per effective horse power per hour (cubic feet	—	—	46.1	38.4	37.4	38	34.4	33	32.7	30	29.5	31.1	29.5	29.4	30.	29.1	29	30	30.1	33.4
Gas per effective horse power per hour (liters	—	—	1310	1090	1060	1080	970	940	930	850	835	892	835	832	850	825	822	850	853	945

* In tests 18 and 19 the amounts of heat recorded as transferred to the water jacket do not fairly represent the heat lost by the hot cylinder gases, for the following reason:—In test 18 but little water was used, the cylinder was becoming hotter, and thus part of the heat was consumed in heating the metal of the cylinder. In test 19, which followed 18 with only five minutes interval, more water was used, and the heat given out by the cooling of the previously heated cylinder is added to that derived directly from the hot gases. If the figures 23 horse power for test 18, and 28 horse power for 19, were substituted for those given in the table, they would probably be much closer to the results of a prolonged test.

ally obtained for the "Otto" engine. This is due chiefly to the poor quality of the gas used. The calculation given further on shows that only 5,495 calories can be obtained from the combustion of 1 cu. meter. For average quality illuminating gas, 6,000 calories is usually taken as a fair figure. Consequently, with $8\frac{1}{2}$ per cent. less gas of average quality an equal amount of heat would be obtained.

An allowance should also be made for the temperature of the gas. In these experiments the gas had a temperature of about 24°C. Now, in winter the temperature of the gas would be reduced nearly, or perhaps quite, to the freezing point as it passed through the meter. From the law that the volume of a perfect gas varies directly as its absolute temperature, pressure remaining constant, it is found that a unit of volume at 24° becomes $\frac{273}{273+24} = 0.92$ volume at 0°C. That is, at 0°, 0.92 vol. has the same weight, and consequently the same heating power that 1 vol. has at 24°. It will be readily admitted that 5 per cent., or more, difference in the volume of gas consumed might easily result from the time of year at which the experiment was made.

The following table shows the effect of making these allowances. The first column gives the average of all the tests at full power, being the actual consumption of the gas used. The other columns give the calculated equivalent values. The temperature 0°C was taken as a convenient standard:

GAS CONSUMPTION (hourly).

ENGINE EXERTING ITS MAXIMUM POWER.

		Average with Hoboken gas.	This amount reduced to 0°C.	Equivalent quantity of ordinary gas.	This amount reduced to 0°C.
Gas per indicated H. P.	cubic ft.	24.5	22.5	22.4	20.6
	liters.	694	637	634	583
Gas per effective H.P.	cubic ft.	30.1	27.7	27.6	25.4
	liters.	853	784	781	719

It is safe to say that 21 cubic feet (600 liters) per hour of good quality illuminating gas at ordinary temperature is sufficient to develop one horse-power with the Otto engine. In fact, this result has frequently been obtained.

The pressure in the gas mains has no appreciable effect upon the volume of the gas, as it causes a contraction of not more than $\frac{1}{300}$.

The table of results at varying power gives the results of tests made when there was not sufficient resistance to make the engine take gas every time. This is the ordinary condition of running, for it is well to have a reserve of power for the governor to call upon. The gas consumption with varying power is seen to be nearly constant per indicated horse-power; but, per actual horse-power the amount of gas used necessarily increases, since the friction becomes greater in proportion to the useful work. These results display the merit of the governor. Whenever there is an excess of speed the supply of gas is cut off until the speed diminishes. In this way the governor insures the greatest possible economy when the engine is exerting less than its maximum power.

5. RATIO OF AIR TO GAS.

The ratio of air to gas was found, by actual measurement of both, to be about seven to one, when the engine was working most economically. Although with better gas the ratio would be slightly increased, yet it could not equal that usually given for the "Otto" engine —ten to one, or thereabouts. The ratio is commonly obtained from a measurement of the gas consumption alone, the air being reckoned as the volume of the piston displacement, less the measured amount of gas. This is not an accurate method, as is shown by the indicator diagram (Fig. 4). The pressure in the cylinder is sensibly below the atmospheric at the end of the out stroke, and it is manifestly unfair to compare volumes when the pressures are different. If, however, the volume represented on the indicator card between the points 1 and 3, (at which points the gases enclosed in the cylinder are at atmospheric press-

ure) be used in calculation, instead of the entire piston displacement, a much closer result will be obtained. The ratio determined by means of two meters is, however, much more satisfactory than a calculated result.

When the proportion of air is increased by partly closing the gas valve, the card obtained is like B or C, Fig. 6; the explosion line is much more inclined, the mean effective pressure is less, consequently also the indicated horse-power. The gas consumption per indicated horse-power is not much changed, but per effective horse-power it becomes considerably greater, showing the false economy of throttling the gas supply. A comparison of tests 16 and 20, in which the conditions other than the ratio of air to gas are nearly identical, shows very plainly the disadvantage of using too little gas.

6. Temperature of Water Jacket.

From the tables it appears that the amount of heat carried off by the water jacket is about half of the total heat of combustion of the gas burned. When the cylinder is kept cool by a plentiful supply of water, the quantity of heat carried away appears to be greater than when less water is used, and the cylinder allowed to become warmer.

From this, one is led to expect a greater per-centage of useful work with less water. But a careful comparison of the results fails to show that any marked difference in either the indicated or the actual work is caused by varying the temperature of the water jacket.

It is probable that much more heat is lost by direct radiation when the cylinder is warm than when it is cool, and that this accounts in part, at least, for the apparent difference in the quantity of heat carried away by the water jacket in the two cases.

7. Thermal Constants for the Gas used.

Analysis of Gas.

The analysis of the gas used in the tests, as determined by Thomas B. Stillman, Ph. D. of the Stevens Institute of Technology, is given on next column:

		By volume.
H	Hydrogen.....	.395
CH_4	Marsh gas.....	.373
N	Nitrogen.....	.082
C_2H_2, &c.	Heavy hydrocarbons.....	.066
CO	Carbonic oxide..	.043
O	Oxygen.....	.014
H_2O_1, CO_2, H_2S, &c.	Water-vapor, impurities, &c...	.027
		1.000

By weight its composition is found to be:

	Cu. meters.		Densities*		Kilos. per cu. m.	W't p. unit.
H	.395	×	.087	=	.035	.058
CH_4	.373	×	.694	=	.258	.426
N	.082	×	1.215	=	.099	.163
C_2H_2, &c.	.066	×	1.84	=	.121	.200
CO	.043	×	1.215	=	.052	.086
O	.014	×	1.388	=	.019	.031
H_2O_1, &c.	.027	×	~.8	=	.022	.036
	1.000	×	.606	=	.606	1.000

By "density" is meant the weight of one cubic meter in kilogrammes. As will be seen from the above, one cubic meter of the gas in question weighs 0.606 kilos.

8. Heating Power of the Gas.

Upon complete combustion the gas develops heat per cubic meter, as follows:

	Calories.†				Calories.
from H	29060	×	.035	=	1020
" CH_4	11710	×	.258	=	3020
" C_2H_2, &c.	11000	×	.121	=	1330
" CO	2400	×	.052	=	125
					per cu. m. 5495c

and per kilog. gas $\frac{5495}{.606} = 9070$ calories.

Expressed in British measures, one cubic foot of gas develops 617.5 heat units.

9. Air necessary for complete Combustion and the Products of Combustion.

In order to determine the amount of air to be supplied for complete combustion, it is necessary to ascertain the quantity of oxygen that is taken into chemical com-

* Schöttler: Die Gasmaschine, p. 77.
† Same, p. 80.

bination by the several combustible constituents of the gas.

$$2H+O = H_2O$$
by volume $2+1 = 2$
by weight $2+16 = 18$

$$CH_4+4O = CO_2+2H_2O$$
by volume $2+4 = 2+4$
by weight $16+64 = 44+36$

$$C_2H_6+9O = 3CO_2+3H_2O$$
by volume $2+9 = 6+6$
by weight $42+144 = 132+54$

$$CO+O = CO_2$$
by volume $2+1 = 2$
by weight $28+16 = 44$

The combining proportions per unit of the several constituents is:

By volume—

$$1H + \tfrac{1}{2}O = 1H_2O$$
$$1CH_4 + 2O = 1CO_2+2H_2O$$
$$1C_2H_6+4\tfrac{1}{2}O = 3CO_2+3H_2O$$
$$1CO + \tfrac{1}{2}O = 1CO_2$$

By weight—

$$1H + 8O = 9H_2O$$
$$1CH_4 + 4O = \tfrac{11}{4}CO_2+\tfrac{9}{4}H_2O$$
$$1C_2H_6+\tfrac{24}{7}O = \tfrac{22}{7}CO_2+\tfrac{9}{7}H_2O$$
$$1CO + \tfrac{4}{7}O = \tfrac{11}{7}CO_2$$

The volume of oxygen required for the combustion of 1 volume of gas is:

H	$.395\times\frac{1}{2}$	$=.197$
CH_4	$.373\times 2$	$=.746$
C_2H_6	$.066\times 4\frac{1}{2}$	$=.297$
CO	$.043\times\frac{1}{2}$	$=.022$
		1.262
less O in gas .014	....	.014
		1.248

Taking oxygen as 21 per cent. in atmospheric air the volume of air required is

$$\frac{1.248}{.21} = 5.94 \text{ per volume gas.}$$

Since air weighs 1.251 kilos. per cu. meter the ratio by weight is

$$\frac{5.94\times 1.251}{1\times .606} = 12.26 \text{ air to gas 1.}$$

From the combustion of 1 unit weight of gas with 12.26 air there results 13.26 units weight of a mixture the composition of which will be:

CO_2	(CH_4)	$.426\times\frac{11}{4}=1.171$	1.93
	(C_2H_6)	$.200\times\frac{22}{7}=.629$	
	(CO)	$.086\times\frac{11}{7}=.135$	
H_2O	(H)	$.058\times 9=.522$	1.74
	(CH_4)	$.426\times\frac{9}{4}=.958$	
	(C_2H_6)	$.200\times\frac{9}{7}=.257$	
N	from the air	.9407	9.57
	in gas itself	.163	
Impurities in gas			0.03
			13.27

Per unit weight of mixture the composition will be:

CO_2	.146
H_2O	.131
N	.721
Impurities	.002
	1.000

The volume which 13.27 kilos. of products of combustion will occupy is found from the known volumes of the constituent gases as follows:

	kilos.	cu. m. per kilo.	cu. m.
CO_2	$1.93\times$	$.524=$	1.011
H_2O	$1.74\times$	$1.28=$	2.227
N	$9.57\times$	$.823=$	7.876
Impurities	$.03\times$	$\sim.9=$	.027
			11.141

The products of combustion then occupy 11.141 cu. m. to every kilog. of gas. To find the ratio per cu. meter of gas we have simply to multiply by .606, the number of kilos in a cubic meter, and we get 6.751 as the result. As there is necessary 6.94 cu. m. of mixture of air and gas to every cu. m. gas, it is seen that by combustion a contraction of 2.7 per cent. takes place.

When there is an excess of air present, as is always the case in practice, the contraction becomes less in proportion, and may be considered to be about 2 per cent. In the following thermodynamic computations no account is taken of this contraction.

10. Specific Heats and their Ratio..

The specific heats of the products of combustion are determined from the specific heats of the several component gases as follows:

Specific heat at constant pressure (water=1).

$$C_p = \left\{ \begin{array}{ll} .2169 \times .146\ (CO_2) & = .0317 \\ .4805 \times .131\ (H_2O) & = .0629 \\ .2438 \times .721\ (N) & = .1758 \\ \sim .4 \times .002 (\text{impurities}) & = .0008 \end{array} \right\} .2712$$

Specific heat at constant volume (water 1)

$$C_v \left\{ \begin{array}{ll} .1714 \times .146\ (CO_2) & = .0250 \\ .3694 \times .131\ (H_2O) & = .0484 \\ .1727 \times .721\ (N) & = .1245 \\ \sim .3 \times .002\ (\text{impurities}) & = .0006 \end{array} \right. .1985$$

The ratio of these specific heats is the exponent of adiabatic expansion and is found to be:

$$\gamma = \frac{C_p}{C_v} = \frac{.2712}{.1985} = 1.366.$$

$$C_v = \frac{(.1985 \times 13.26) + (.1684 \times 1.42)}{14.68} = .196$$

$$\gamma = \frac{C_p}{C_v} = \frac{.268}{.196} = 1.37$$

THE WORKING CYCLE.

11. THE INDICATOR DIAGRAM.

The indicator diagram (Fig. 2) is a fair sample of those taken during the tests at full power.

Beginning at the point 1, the lowest line of the diagram represents the pressure during the first forward stroke, while gas and air are entering the cylinder. This line lies at a nearly uniform distance below the atmospheric line, as is shown more clearly on the diagrams (Figs. 4 and 5) taken with a very light spring.

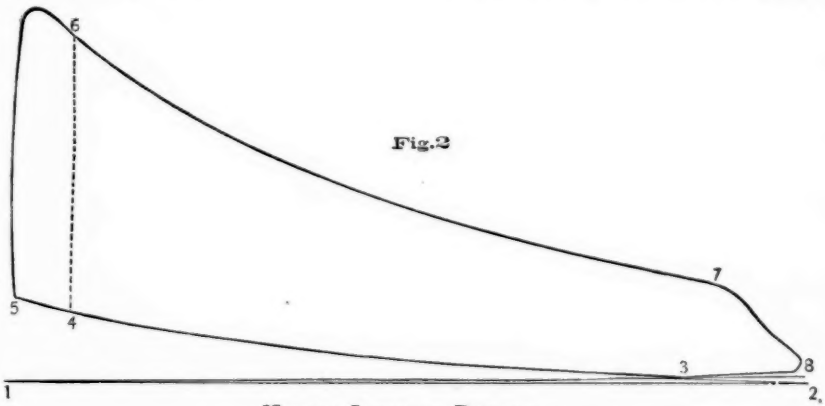


Fig. 2

NORMAL INDICATOR DIAGRAM.

Since there is always an excess of air present, these values will be somewhat modified by that fact. From the meter records of test 19 the ratio of air to gas by volume was found to be 6.63 to 1; by weight the ratio is

$$\frac{6.63 \times 1.251}{1 \times .606} = 13.68.$$

Since for complete combustion only 12.26 parts of air by weight are needed, there are 1.42 parts in excess. The specific heats of air being $C_p = .2375$ and $C_v = .1684$; the effect of the excess of air will be to reduce the specific heat slightly.

$$C_p = \frac{(.2712 \times 13.26) + (.2375 \times 1.42)}{14.68} = .268$$

This line, 1, 2, shows a negative pressure of about 0.15 atmospheres. At 2 the inlet valve closes, and by the return stroke the gases are compressed into the clearance space at the back end of the cylinder. This compression is represented by the line 2, 3, 4, 5, which crosses the atmospheric line at 3, and shows a pressure of 2 atmospheres at 5.

One revolution of the engine is now completed, and the charge is ignited just as the crank is passing the center. The rapid burning of the gas liberates a large amount of heat, increasing the temperature and pressure, which reaches about 9 atmospheres as a maximum. The line, 5, 6, is called the explosion line, although the action is better described as rapid

combustion than as an explosion. The gases now expand during the second forward stroke, and exert upon the piston energy which, by means of the fly wheels, carries the engine through the remainder of the cycle. At 7 the exhaust valve opens, allowing the burned gases to escape.

The line 8, 1, shows the pressure while these gases are being expelled by the second return stroke of the piston.

When the governor prevents the admission of gas to the cylinder the cycle is somewhat modified. After compression of the air no explosion can take place since there is no combustible mixture present. The expansion line then follows closely the previous compression line, and the cycle is completed by expulsion of the air. Two revolutions are required to complete the cycle when the engine takes gas every charge, and four, six, eight, or sometimes ten revolutions may occur before the engine returns to its original state.

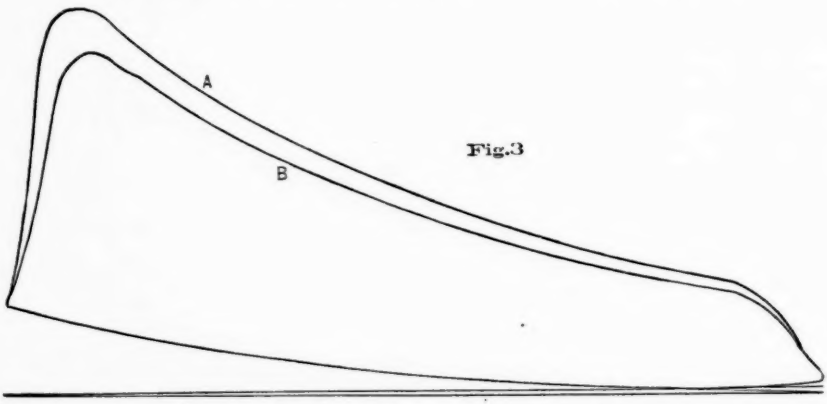


Fig. 3

DIAGRAM WITH REGULAR AND WITH INTERMITTED ACTION.

In Fig. 3 are given copies of two cards, one A, taken during test 1, when the engine took gas once in five times; the other, B, during test 14, when the engine took gas every time. Since in test 1 four charges of air passed through the cylinder after every explosion, the products of combustion were almost completely expelled, leaving the clearance space filled with nearly pure air at a temperature little above the atmospheric. A larger charge of gas could thus be drawn into the cylinder and still have sufficient oxygen for combustion. The result is shown by the greater area of diagram A. The mean effective pressure is not, however, proportionately greater, since the correction for work done in drawing in gases has to be applied five times to A, and only once to B.

It will be noticed, especially by the light spring diagram (Fig. 4), that the pressure between the points 9 and 10 falls below the atmospheric. This is undoubtedly due to the rapid cooling of the hot discharged gases in the exhaust vessel and pipe outside the engine. The contraction of these gases from this cooling is greater than the piston displacement during the early part of the return stroke, thus causing a partial vacuum within the cylinder. To show that this is the real cause, and that it is not due to any inaccuracy of the indicator, a diagram (Fig. 5), taken when the engine was running without taking gas every time, is inserted.

After an explosion the pencil follows the line *a*, *b*, *c*, *d*, the same as 8, 9, 10, 1, on the other diagram. During the next forward stroke no gas is taken in, and the line *d*, *e*, corresponding to 1, 2, is drawn. Then follows the compression line *e*,*f*,*g*,*h*, the same as 2, 3, 4, 5. Since there is no explosion this time, the pencil returns along the wavy line *i*, *j*, *k*, *l*, nearly coincident with the compression line. At

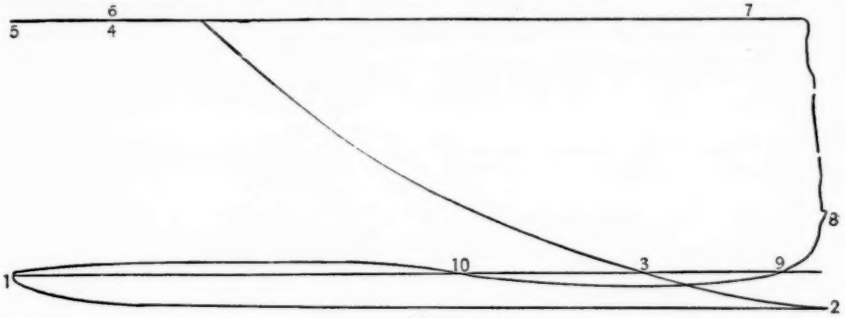
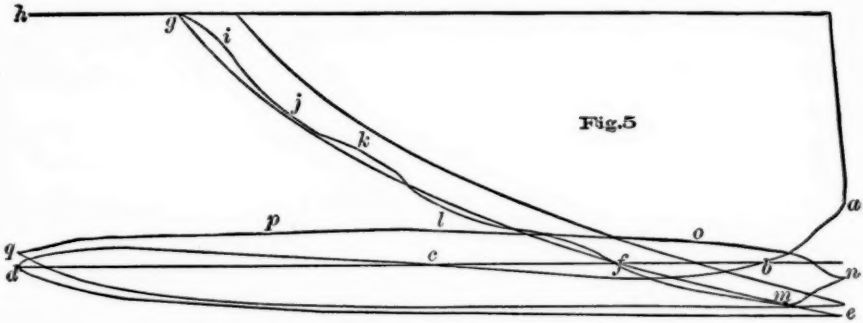
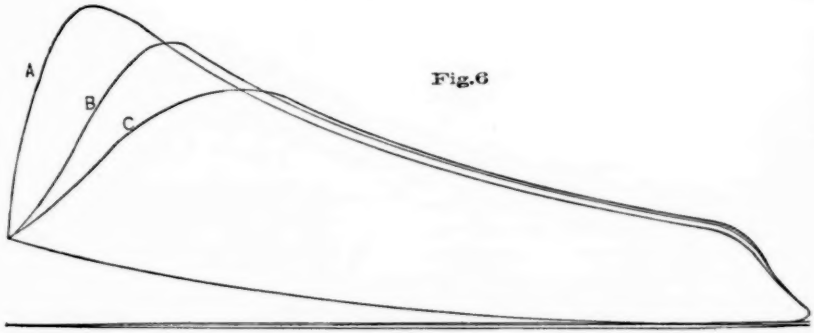


Fig.4

DIAGRAM TAKEN WITH LIGHT SPRING.



LIGHT SPRING, INTERMITTED ACTION.



SERIES OF INDICATOR CARDS.

m the exhaust valve opens, allowing air to enter from without. The pencil does not return to *e*, but moves to *n*, nearly on the atmospheric line. Since the gases have not been heated, there can be no contraction to counteract the piston displacement, and on the return stroke the exhaust line *n*, *o*, *p*, *q*, immediately rises above the atmospheric, as would be inferred. That it keeps above the other exhaust line *b*, *c*, *d*, for the whole length of the stroke is a still further confirmation of this reasoning.

12. Pressures and Temperatures.

Before the indicator card can be used in thermodynamic calculations, it is necessary to determine the absolute volumetric relations represented on the diagram.

The volume of the clearance space was determined by weighing the water required to fill it. It was found to be 7.94 liters. The piston displacement is 13.015 liters. Consequently the clearance space is 38 per cent. of the total cylinder volume, and is represented on the scale of the diagram by 73 millimeters. The line of zero volume, therefore lies 73 mm. to the left of points 1 and 5 (Fig. 2).

The compression line 2, 3, 4, 5, crosses the atmospheric line at 3, 170 mm. from the zero line, representing a volume 0.885 of the total cylinder space.

It is necessary first to determine the temperature of the contents of the cylinder at the point 3 before compression. The meters show that 1.40 liters gas and 9.25 l. air, at a temperature of 22° C, were admitted to the cylinder every charge during test 19, the one chosen for calculation. There were in the clearance space 7.94 l. products of combustion from the previous charge at a temperature of 410°, as given by the pyrometer.

Volumes at constant pressure are proportional to absolute temperature. These volumes reduced to 0° C become,

for entering gases $10.65 \times \frac{273}{296} = 9.82$ liters.

for product of combustion $7.94 \times \frac{273}{683} =$ 3.18 liters.

The weight of 1 liter of entering gases (air 6.63 vols., gas 1 vol.) at 0° is 1.16 grams. The weight of 1 liter of products of combustion (burned gases 9.6 vols., excess of air 1 vol.) at 0° is 1.19 grams.

∴ The entering gases weigh $9.82 \times 1.16 = 11.3$ grams., and the products of combustion weigh $3.18 \times 1.19 = 3.78$ grams. The temperature at constant pressure of a mixture of 11.3 grams entering gases at 296° absolute, and 3.78 grams burned gases at 683° absolute, considering the specific heats the same for the two components, will be,

$$\frac{(11.3 \times 296) + (3.78 \times 683)}{11.3 + 3.78} = 393° \text{ abs.}$$

From the thermodynamic formula $\frac{pv}{\tau} = \text{const.}$ for perfect gases, we find for the various points numbered on the card the values given below.

For the point 3,

$p_3 = 1$ at. $v_3 = 0.885$ cylinder volume.

$\tau_3 = 393°$ abs. $T_3 = 120°$ C.

$$\therefore \frac{p_3 v_3}{\tau_3} = 0.002252 = \delta a \text{ const.}$$

For the point 5,

$p_5 = 3.09$ at. $v_5 = 0.38$ cyl. vol.

$$\therefore \tau_5 = \frac{3.09 \times 0.38}{.002252} = 522° \text{ abs. } T_5 = 249°$$

For the point 6,

$p_6 = 10$ at. $v_6 = 0.44$ cyl. vol.

$$\therefore \tau_6 = \frac{10 \times 0.44}{.002252} = 1930° \text{ abs. } T_6 = 1657°$$

For the point 7,

$p_7 = 3.5$ at. $v_7 = 0.92$ cyl. vol.

$$\therefore \tau_7 = \frac{3.5 \times 0.92}{.002252} = 1432° \text{ abs. } T_7 = 1159°$$

Upon the opening of the exhaust valve at point 7 the gases begin to escape from the cylinder, and the absolute volumes are no longer shown by the indicator diagram. If, however, the expansion from 7 be considered adiabatic, values can be found for the point where the pressure becomes atmospheric. Designate such point as 9′ since it corresponds to the point 9 on the diagram. The exponent of adiabatic expansion γ, has been already determined.

$$pv^\gamma = \text{const.}$$

$$p_9' v_9'^\gamma = p_7 v_7^\gamma$$

$p_9' = 1$ at. $p_7 = 3.5$ at.

$v_7 = 0.92$ cyl.

$$\therefore v_9' = p_7^{\frac{1}{\gamma}} v_7 = 3.5^{0.713} \times 0.92 = 2.33 \text{ cyl.}$$

$$\therefore \tau_9 = \frac{1 \times 2.33}{.002252} = 1035° \text{ abs. } T_9' = 762°$$

For the case in which the engine does not take gas every time the values for pressure and temperature are quite different. This case is represented by diagram A. (Fig. 3). Taking the temperature of the charge before compres-

sion at 300° absolute, instead of 393° as found above, the maximum temperature reached is 1727° abs., instead 1930, although the pressure in A is one-half an atmosphere higher at the maximum.

13. Equations of Lines.

Since the compression and expansion lines are nearly adiabatic, the general formula, pv^x = constant, gives very accurate equations for those lines when the values of x are determined.

For the expansion curve x, is determined as follows,

$$p_6 v_6^{\,x} = p_7 v_7^{\,x}.$$

Using *Naperian* logarithms,

$$\log p_6 + x.\log v_6 = \log p_7 + x.\log v_7$$

$$x = \frac{\log p_6 - \log p_7}{\log v_7 - \log v_6}$$

$$x = \frac{\log 10 - \log 3.5}{\log 0.92 - \log 0.44} = 1.363$$

For the compression line,

$$x = \frac{\log p_5 - \log p_2}{\log v_2 - \log v_5} = \frac{\log 3.09 - \log 1}{\log 0.885 - \log 0.38} = 1.335$$

14. Indicated Heat.

"The mechanical equivalent of the heat absorbed or given out by a substance in passing from one given state, as to pressure and volume, to another given state, through a series of states represented by the coördinates of a curve on a diagram of energy, is represented by the area included between the given curve, and two curves of no transmission of heat drawn through its extremities, and indefinitely prolonged in the direction of increase of volume."*

The above theorem furnishes a method for finding the amount of heat received or rejected along the several lines of the diagram.

The heat received along the explosion line 5, 6, is the thermal equivalent of the area between the indefinitely extended adiabatics from 5 and 6. This area is, for convenience, divided by the vertical line 6, 4; the area 4, 5, 6 was measured on the card, and found to be 4.2 sq. centimeters.

Let A = the area under the adiabatic from point 6, indefinitely extended.

* Rankine's "Steam Engine," p. 303.

Let B = the area under the adiabatic from point 4, indefinitely extended.

Then the A − B + (area 4, 5, 6) will be the area sought.

The equation of the adiabatic from 6 is,

$$p_6 v_6^{\gamma} = pv^{\gamma} = \text{const.} \quad \therefore \quad p = p_6 v_6^{\gamma}\, v^{-\gamma}$$

$$A = \int p\,dv = \int_{v_6}^{v_\infty} p_6 v_6^{\gamma}\, v^{-\gamma} dv$$

$$= \frac{1}{1-\gamma} p_6 v_6^{\gamma} \left[v^{1-\gamma} \right]_{v_6}^{v_\infty} = \frac{1}{1-\gamma} p_6 v_6^{\gamma} \left(v_\infty^{1-\gamma} - v_6^{1-\gamma} \right)$$

$v_\infty^{1-\gamma} = 0$, since $1-\gamma$ is negative, hence,

$$A = \frac{1}{\gamma - 1} p_6 v_6^{\gamma} v_6^{1-\gamma} = \frac{1}{\gamma - 1} p_6 v_6.$$

In the same way it can be shown that

$$B = \frac{1}{\gamma - 1} p_4 v_4.$$

$$\therefore \quad A - B = \frac{1}{\gamma - 1}(p_6 v_6 - p_4 v_4),$$

and since $v_6 = v_4$,

$$A - B = \frac{1}{\gamma - 1}(p_6 - p_4)\, v_6 = 96.5 \text{ sq. centimeters, taking } \gamma \text{ as } 1.37.$$

A − B + area 4, 5, 6 = 96.5 + 4.2 = 100.7 sq. cm.

Reduced to calories per charge, this becomes 4.67 calories.

With our present knowledge of the behavior of the permanent gases, it is not certain that the specific heats of these gases remain constant at the high temperatures attained in the gas engine. If, however, we consider their ratio constant, a comparison of γ with the exponent x for the expansion line 6, 7, shows that this line is almost exactly adiabatic, and that there is no appreciable transmission of heat along it.

The compression line 2, 3, 4, 5 is also nearly adiabatic, but a calculation similar to that given for the explosion line shows a rejection of 0.05 calories.

The total amount of heat received during that part of the cycle represented by the lines 3, 4, 5, 5, 6, and 6, 7 is 4.67 + 0 − 0.05 = 4.62 calories per charge.

This indicated heat disappears in two ways:

1. As indicated work.

2. As heat wasted after the exhaust valve opens.

1. The indicated work measured by a planimeter and reduced to calories gives 1.33.

2. When the exhaust valve begins to open at 7, $\tau_7 = 1432°$. If the contents of the cylinder be supposed to expand adiabatically, the absolute temperature at atmospheric pressure becomes 1035°. The temperature obtained from the pyrometer in the exhaust pipe was 683° abs. This difference in temperature shows that heat is lost by the gases cooling in the cylinder and exhaust pipe, and shows that the expansion beyond point 7 was not adiabatic.

The amount of heat included in (2) may, for convenience of calculation, be separated into three parts:

a. Work of adiabatic expansion of the cylinder contents to atmospheric pressure.

b. Heat given out by the cylinder contents cooling from 1035° to 683° abs. at constant pressure.

c. Heat given out by that part of the cylinder contents representing one charge in cooling still further from 683° to 296°.

a is found to be equivalent to 0.58 calories.

b. The contents of the cylinder weigh 11.3 grams for the charge of gas and air, and 3.78 grams for the gases remaining in the clearance space, making 15.08 grams in all. The specific heat of this mixture at constant pressure may be taken at .27

$$.01508 \times .27 \times (1035 - 683) = 1.44 \text{ calories.}$$

c. $.0113 \times .27 \times (683 - 296) = 1.18$ calories.

Adding *a*, *b*, and *c*, we find for (2) $.58 + 1.44 + 1.18 = 3.2$ calories.

Adding (1) and (2) we find,

$1.33 + 3.2 = 4.53$ calories accounted for out of 4.62 calories indicated as heat received, as near an agreement as could be expected.

15. Discrepancy Explained—dissociation.

The total heat of combustion of one charge, .0014 cu. meters of the gas used, is 7.69 cal. The difference between this and the indicated heat, 4.62 cal., is 3.07 cal., or 40 per cent. of the total heat which is left unaccounted for by the indicator card.

As we find from the tests that about half of the total heat of the gas goes into the water jacket, a considerable quantity of heat must be so given out during that part of the cycle represented by the line 6, 7, where the temperature of the gases in the cylinder is high. Since this line is very nearly adiabatic, an amount of heat equal to that absorbed by the water jacket must be received from some source, necessarily from the gas itself.

It is a well established fact that heat decomposes chemical compounds. Carbonic acid is thus separated into carbonic oxide and oxygen at a comparatively low temperature. At the temperature attained after an explosion in the gas engine, it is almost certain that this action, known as *dissociation*, occurs and prevents the complete combustion of the gas taking place instantly. As the temperature gradually decreases from expansion, further burning ensues. It is quite possible that the gas is not fully burned until after the opening of the exhaust valve.

16. Efficiency.

As the cycle in which a gas engine works does not even approximate to the theoretical cycle of Carnot, it seems futile to apply his formula for efficiency.

The indicated work represents 18 per cent. of the total heat of combustion of the gas. The actual useful work is 14½ per cent.

An efficiency sometimes given for the gas engine, derived from the indicator diagram alone, is the indicated work divided by the indicated heat, giving about 30 per cent. This is manifestly incorrect, since the indicated heat is not the whole heat of the gas.

The best steam engines utilize only 10 per cent. of the total heat of combustion of the coal, and small engines rarely exceed 5 per cent., so that the gas engine is by far the more perfect heat engine.

17. Disposition of the Heat.

Heat is disposed of in a gas engine in these ways:

(1). As indicated work, including useful work and friction.

(2). In the hot expelled gases.

(3). In the water jacket.

(4). In radiation, etc.

Taking the figures directly from test 19, but making allowance for probable error in the figure for water jacket, it is found that

(1)=1.33	calories	or 17	per	cent.
(2)=1.18	"	15½	"	"
(3)=4.00	"	52	"	"
(4)=1.18	"	15½	"	"

the sum 7.69 calories, being the total heat of combustion of the gas.

Commercial Efficiency of the Gas Engine.

18. Relative Economy of Gas, Steam and Hot-Air Engines.

In making a comparison of this kind it is necessary to consider,

(1). The cost of gas or coal consumed.

(2). The cost of water used.

(3). Lubrication.

(4). The cost of attendance.

(5). Depreciation and repairs.

(6). Interest on capital invested.

(1). The average consumption of gas in a gas engine per effective horse-power per hour, including igniting flames, is about 30 cubic feet.

The consumption of coal per effective horse-power per hour by small steam engines is about 7 lbs.

(2). The water used in the water jacket of a gas engine will not enter into the estimate, since by the use of tanks the same water may be used continuously.

The water supplied to the boiler of the steam engine here considered amounts to ⅝ cu. ft per horse power per hour.

(4). A gas engine requires little or no attendance. A man can accomplish ⅝ of a day's work and still take full charge.

Steam engines of this size require from ½ to 1 day's attention, depending upon the proximity of the engine and boiler.

(5). As regards depreciation, it is safe to say that gas and steam engines have about equal terms of life; for, while gas engines have less complication of working parts than steam engines, yet they are subject to more severe and abrupt strains.

(6). The interest will necessarily be directly proportional to the amount of capital invested.

The following summary shows the relative cost of a day's running:

Gas Engine, 8 H. P. actual, 10 hours.

(1) 2,400 cu. ft. gas @ $2.50 per 1,000	$6.00
(2) Water	0.00
(3) Lubrication	0.20
(4) ⅓ day's labor @ $2.00	0.33
(5) Depreciation, &c., at 12% per year $\frac{12}{360}$% on $1,075	0.36
(6) Interest at 5% per year $\frac{5}{360}$% on $1,075	0.15
Daily expense	$7.04

Steam Engine, 8 H. P. actual, 10 hours.

(1) Coal $\frac{560}{2240}$ tons @ $5.00	$1.25
(2) Feed water 65 cu. ft. @ $1.25 per 1,000	0.08
(3) Lubrication	0.15
(4) ½ day's labor at $2.00	1.00
(5) Depreciation, &c., at 12% per year $\frac{12}{360}$% on $800	0.27
(6) Interest at 5% per year $\frac{5}{360}$% on $800	0.11
Daily expense	$2.86

The following figures have been obtained for the expense of running a small hot-air engine. This engine has been running in a printing office in New York City for 18 years. It uses 4½ lbs. of coal per H. P. per hour; every third year relining costs $100.

Hot-Air Engine, 2½ H.-P. actual, 10 hours.

(1) Coal $\frac{115}{2240}$ tons @ $5	$0.25
(2) Water	0.00
(3) Lubrication	0.10
(4) Attendance same as for gas engine	0.33
(5) Depreciation &c., @ 10% per year $\frac{10}{360}$% on $750	0.21
(6) Interest @ 5% per year $\frac{5}{360}$% on $750	0.10
Daily expense	$0.99

The cost of one horse-power per hour is,

with gas engine.....8¾ cents.
with steam engine...3½ "
with hot-air engine..4 "

For intermittent work the gas engine is much more economical than the above figures indicate; and this fact, together with its safety, cleanliness and convenience, makes the gas engine very desirable where small powers are required.

19. Cheaper Gas.

With cheaper kinds of gas it becomes possible to reduce the figures for gas engines as low if not lower than those obtained for steam engines. In England and Germany, where the cost of illuminating gas varies from $0.50 to $0.75 per 1,000 cu. ft., the above figures would be reduced 60 per cent., making the daily expense of the gas engine about $2.75.

It should be remembered that *illuminating* gas is not required for the gas engine. The manufacture and distribution in cities of some cheap gas especially adapted for use in gas engines may soon become a prominent industry; and, with economy added to its other merits, the gas engine may largely supplant steam for manufacturing and other purposes.

At the British Associatlon meeting a paper by Prof. J. A. Ewing was read, on the magnetic susceptibility and retentiveness of iron and steel. This paper was a preliminary notice of some results of an extended investigation which the author had been conducting for three years in Japan. Experiments with annealed rods and rings of soft iron wire showed that that material possesses the property of retentiveness in a very high degree. As much as 90 and even 93 per cent. of the induced magnetism survived the removal of the magnetizing force. The extraordinary spectacle was presented of pieces of soft iron entirely free from magnetic influence, nevertheless holding an amount of magnetism, per unit of volume, greatly exceeding what is ever held by permanent magnets of the best tempered steel. The magnetic character of the iron in this condition was, however, highly unstable. The application of a reverse magnetizing force quickly caused demagnetization, and the slightest mechanical disturbance had a similar effect. Gentle tapping removed the residual magnetism completely. Variations of temperature reduced it greatly, and so did any application of stress. On the other hand, the magnetism disappeared only very slowly, if at all, with the mere lapse of time. The residual magnetism in hardened iron and steel was much less than in soft annealed iron. The maximum ratio of intensity of magnetism to magnetizing force during the magnetization of soft iron was generally 200 or 300, and could be raised to the enormous figure of 1590 by tapping the iron while the magnetizing force was being gradually applied. A number of absolute measurements were made of the energy expended in carrying iron and steel through cyclic changes of magnetization; and the effects of stress on magnetic susceptibility and on existing magnetism were examined at great length. The whole subject was much complicated by the presence of the action which, in previous papers, the writer had named *Hysteresis*, the study of which, in reference both to magnetism and to thermo-electric quality, had formed a large part of his work.

An Asphalte Mortar.—The *Centralblatt der Bauverwaltung* describes a patented composition made at a factory in Stargard, Pomerania, which has for some years past been used with perfect success on the Berlin-Stettin railway for wall copings, water-tables, and similar purposes requiring a water-proof coating. The material is composed of coal tar, to which are added clay, asphalte, resin, litharge and sand. It is, in short, a kind of artificial asphalte, with the distinction that it is applied cold, like ordinary cement rendering. The tenacity of the material when properly laid, and its freedom from liability to damage by the weather, are proved by reference to an example in the coping of a retaining wall which has been exposed for four years to the drainage of a slope 33ft. high. This coping is still perfectly sound and has not required any repair since it was laid down. Other works have proved equally satisfactory. In applying this mortar, as it is termed, the space to be covered is first thoroughly dried, and after being well cleaned is primed with hot roofing varnish, the basis of which is also tar. The mortar is then laid on cold to thickness of about $\frac{3}{8}$ inch, with either wood or steel trowels, and is properly smoothed over. If the area covered is large, another coating of varnish is applied, and rough sand strewn over the whole. The water-proof surface thus made is perfectly impregnable to rain or frost, and practically indestructible. The cost of the material laid is estimated at 5d. per sq. ft.; and this price can be reduced at least 1d. for large quantities put down by experienced workmen.

COVERED SERVICE-RESERVOIRS.

By WILLIAM MORRIS, M. Inst. C. E.

From Proceedings of the Institution of Civil Engineers.

The author, in treating of this subject, has confined himself to those reservoirs of which he has some practical knowledge. For this reason he has not attempted a description of those ancient reservoirs, of which Puteoli and Constantinople are examples, which prove that the Roman and other ancient nations, who lived in warm climates, long ago appreciated the importance of keeping water pure and cool for potable purposes, and that although the use of covered reservoirs in connection with the waterworks of the present day is of somewhat recent date, it is by no means a modern refinement.

Another example of covered reservoirs, on a small scale, consists in underground tanks, for the storage of rain-water. These are largely used for keeping such water sweet and wholesome; indeed, the cities of Venice and Cadiz are almost entirely dependent on underground cisterns for their supply of water, and as there is practically no smoke in these cities, if the roofs, pipes and tanks are kept clean, the water is palatable.

Covered Service-reservoirs, as technically understood, are intended for the distribution rather than for the storage of water; but if attention be confined to the description of Covered Service-Reservoirs in connection with modern waterworks, the subject is still a wide one, and the author must apologise for his inadequate treatment of it.

Without attempting to trace the introduction of covered reservoirs into this country, it does not appear, from official returns, that any were used by the London Water Companies till after the year 1850; at which time filtration had been partially introduced. With the adoption of filtration, however, it soon became evident that covered reservoirs were necessary for the storage of filtered water, and accordingly the Metropolis Water Act, 1852, which required all water (except water pumped from wells) to be filtered, specially enacted that all reservoirs for filtered water within 5 miles of St. Paul's should be covered. It would appear that this enactment was more particularly intended to preserve the water from contact with the smoky and polluted atmosphere of London; but the objection to uncovered service reservoirs is by no means confined to those exposed to the smoky atmosphere of large towns, at least, such is the author's experience in the case of water from the Chalk, whether pumped directly from wells or from rivers, such as the Thames and its tributaries which are fed from chalk springs.

When comparatively shallow open reservoirs are filled with such water, vegetable and animal life is quickly developed, especially in summer; the lower forms of vegetation first make their appearance, consisting of myriads of zoospores of algæ. The following note relates to the effect of this growth on the color of water from the River Ravensbourne, from which the Kent Waterworks formerly took their supply. "August 11th, 1851. This day a remarkable change took place in the water in the old filter bed, it became of a greenish milk color; when mixed with alum, it precipitated a large quantity of white substance, which, being examined with the microscope, was found to contain zoospores, pulpy matter and crystals of alum. Boiling had no effect on the color. The next day the water in the filter turned green."

The zoospores subsequently develop into green blanket weed, which is apt to form stoppages in the house service pipes, if it should find its way into the mains; with such forms of vegetation are usually associated water fleas, cyclops, and other animalcules.

The following extract from a report of the author's father, the late Mr. W. R. Morris, M. Inst. C. E., bears on this question:

"The Service-Reservoirs of the Kent Company being without the limits of the Act of Parliament of last Session the

covering is not compulsory, but is not the less necessary. In the summer months the improvement from filtration is lost in the present uncovered reservoirs; just so much as the company's filters have raised the water in the public estimation, equally so will be the dissatisfaction of the tenants, particularly when wholly supplied from these reservoirs."

The reservoirs referred to in this report were the Greenwich Park and Woolwich Common reservoirs, constructed under an agreement between the Admiralty and Kent Waterworks Company, by which it was agreed that these two reservoirs should be constructed at the cost of the Admiralty, the former for the protection in case of fire of Greenwich Hospital and the Dockyard and Victualling Yard at Deptford, and the latter for the protection of the Dockyard and Marine Barracks at Woolwich, these establishments being connected with the reservoirs by special fire mains; under this agreement the Company are bound to maintain a given head of water in the reservoirs, but subject to this condition are at liberty to use them for the supply of their district.

These reservoirs, which contain 1,125,000 gallons and 1,750,000 gallons respectively, were uncovered service-reservoirs, only intended for the purpose of storing water for use in case of fire or accident to the pumping machinery; they hold sufficient water to keep the mains charged at night when the pumping engines are not working, they regulate the pressure in the mains and maintain it practically uniform. Thus, when the draught of water from the mains is in excess of the quantity pumped the reservoirs supply the deficiency; and, on the other hand, when the quantity of water pumped exceeds the draught the excess flows into the reservoirs.

Before these reservoirs were constructed there was no pressure in the mains by night, and it was necessary to start the pumping engines in case of fire, which involved considerable delay.

In some waterworks a special pumping main is laid down from the engines to reservoir, and the whole of the water supplied is pumped into the reservoir before it is distributed; this is not the case at the Kent Waterworks; the mains are all connected with the reservoirs, but a very small portion of the water supplied actually passes into them.

On account of the small quantity of water taken from it, the covering of the reservoir in Greenwich Park was postponed from 1853 till 1871; it was, however, determined to cover the reservoir on Woolwich Common, but, on tenders being invited, the cost was found to be greater than had been anticipated; the project was abandoned for the time, and the bottom of the reservoir was converted into a filter, which arrangement continued for eighteen years, till the draught of water from the reservoir increased beyond its power of filtration; the reservoir was ultimately handed over to the War Office, who granted the Company another piece of land on Woolwich Common for the construction of a covered reservoir.

The first covered reservoirs used by the Kent Waterworks were two, which had been built for the Woolwich, Plumstead and Charlton Pure Water Consumer's Company, from the designs and under the direction of Mr. S. C. Homersham, M. Inst. C. E.

In the reservoir excavated on Plumstead Common the water line is below the original surface of the ground. The structure is of concrete faced with brickwork in cement. The side walls are 2 feet 6 inches thick at the top and 4 feet thick at the bottom; the back of the wall is vertical, while the inside face is battered to a slope of 1 in 8. The reservoir is divided into two compartments by a center wall 5 feet wide at the top, and 7 feet at the base; the length of each compartment at the water line is 100 feet, the width of the one being 52 feet and of the other 50 feet. The floor of the reservoir is also of concrete about 18 inches thick, paved with brick: the corners of the reservoir are curved to a radius of 3 feet 6 inches; the covering arches, thirteen in number, are built with two rings of brickwork, having a span of 7 feet 2 inches and a rise of 1 foot; they spring from cast-iron girders which rest in the center on a wall 18 inches thick with arched openings built to a height of 6 feet above the division wall, and they slope down to and rest on the exterior walls; they are also supported by two cast-iron columns which rest on brick

piers built in the floor. The arches are covered with 9 inches of puddle, to carry off the rain water and prevent it soaking into the reservoir, and finally with gravelly earth laid to a regular slope and covered with grass.

The center wall is paved with York stone about 6 inches above the water line, and forms a gangway through the reservoir to which access is obtained by an entrance door and a flight of steps at the south end; the water enters through an inlet pipe in each compartment 16 inches in diameter, with sluice cocks inside the reservoir, over which York landings are fixed to form platforms for working the same. There are overflow pipes which discharge into a dry well sunk in the gravel. The water-level was indicated by floats, the gauge-rods connected with which are enclosed by brick columns; they are not at present in use, owing to the columns having settled out of the perpendicular.

The reservoir is built on the pebble bed of the Lower Eocene formation, consisting of small rounded pebbles and fine sand. It is perfectly watertight, and contains 650,000 gallons; when full the level of the water is 170 feet above ordnance datum. The cost of this reservoir, which was built in 1854, was £3,442, including boundary wall, &c.

The reservoir on Constitution Hill, Shooter's Hill, was built at the same time as that on Plumstead Common; it was never used by the Plumstead Company, but remained empty for some years till it was purchased by the Kent Waterworks. It is coffin-shaped, the full dimensions being 120 feet by 35 feet, the depth of water is 13 feet. The top-water level is 320 feet above ordnance datum. The roof is similar to that of the Plumstead reservoir, and consists of brick arches springing from fourteen cast-iron girders, supported in the center by cast-iron columns. The side walls are of brick, built with a batter, and stiffened by counterforts; the base is 2 feet 3 inches thick, which is reduced in steps to 1 foot 10½ inches, 1 foot 6 inches and 9 inches. The footings of the wall rest on concrete 18 inches thick. The floor consists of layers of tiles placed on 1 foot of concrete. The whole of the interior surface is rendered in Portland cement.

The reservoir is built on ground which slopes rapidly from south-east to north-west, so that whilst the south end of the embankment is level with the original surface, the north end is 20 feet above it; the slope of the embankment, 1½ to 1, is rather too steep for the soil, which is London clay, and it has slipped in places. For this reason it has not been considered desirable to retain a greater depth of water than 8 feet, to which height the overflow pipe has been adjusted. The reservoir has a capacity of 300,000 gallons, but has never been quite watertight owing to various cracks in the floor; these have been repaired from time to time. Its total cost has been £1,948.

The first covered reservoir constructed by the Kent Company was made from the designs and under the direction of the author's father in 1866, at Chiselhurst. It is of irregular shape, being built on a small corner plot of land in Bickley Park. The reservoir is excavated in ground, which consists of pebble bed, as at Plumstead Common. It is formed with four vaults, each 16 feet wide, of the following lengths: 113 feet, 103 feet, 93 feet and 55 feet; the depth of water is 11 feet; the exterior walls are 14 inches thick, stiffened by piers 2 feet 3 inches square. The piers in the center of the reservoir are 3 feet by 18 inches, supported by longitudinal and cross inverts; arched ribs spring from the top of the piers to support the side walls. The vaulting springs from cast-iron girders resting on the piers and side walls, and is formed of two rings of brickwork at the crown, and of three rings at the haunches. The girders are tied together by wrought-iron rods, 10 feet from center to center. The floor is formed of a layer of concrete, one course of bricks laid flat, and two layers of plain tiles in cement; the whole of the floor and side walls is rendered with cement. In the course of construction some heavy rain caused part of the gravel to fall in at the end marked B, buttresses were therefore added to stiffen the end walls. The top-water line is 315 feet above ordnance datum. The reservoir contains 450,000 gallons. The work, which was executed by Messrs. Aird, cost £2,246.

The Dartford reservoir formed part of the waterworks, constructed by the Dartford Local Board of Health in 1854. The

works comprised an artesian well, pumping engine, and a complete system of pipeage, but on starting the engine some mishap occurred to the well, and the opponents of the waterworks being successful at an election of the Local Board, they determined to spend no more money on the works, and allowed their creditors to seize, sell and remove the pumping engine and boilers; these were sold for £300. The works then remained dormant till 1868, when they were purchased by the Kent Company, the Local Board having obtained parliamentary powers to sell their waterworks to the Company.

The reservoir is circular on plan, 60 feet in diameter at the bottom and 64 feet at the top, with a depth of water of 20 feet. There was neither covering nor artificial bottom to the reservoir when the Company took possession; the bottom has been paved with one course of stock bricks and two courses of plain tiles laid in cement. The roof is formed of arches of hollow gault bricks 5 inches thick, springing from nine rolled joists 12 inches deep, radiating from the center, where they are supported on a cast-iron column; the outer ends rest on the walls of the reservoir. These girders have a slope of 4 feet from the center. The covering arches at the outer end next the wall have a span of 22 feet 9 inches, and a rise of 4 feet; the crown of the arch is level, whilst the span gradually diminishes to nothing in the center; the spandrels are strengthened by brick inverts, and the whole of the upper surface of the roofing is rendered in cement mortar. The cost of the roof was about £375.

The Greenwich Park reservoir was built as an uncovered reservoir from the designs of the late Mr. Thomas Wicksteed, M. Inst. C. E., in 1845, for the protection of the Government establishments at Greenwich and Deptford in case of fire. It is circular on plan, the diameter at the bottom being 154 feet, and at the top 184 feet, with a depth of 8 feet when full; it contains 1,125,000 gallons of water. The top-level of the water is 158 feet above ordnance datum.

It is excavated in the Blackheath gravel, which consists of rounded pebbles mixed with fine sand, forming an excellent foundation; the sides and bottom were of lime concrete 12 inches thick on 9 inches of puddle. They were afterwards paved with bricks laid flat in cement, in consequence of the decayed state of the lime concrete, which was partially destroyed by the action of the weather and the wash of the water against the sides.

The covering, which was completed in 1871, consists of five concentric rings of 9-in. arches, having a span of 16 feet and a rise of 4 feet 6 inches. The outer ring springs from a concrete foundation 3 feet wide and 3 feet deep half way down the sloping bank, and carried 18 inches into the solid ground; the other arches spring from rings of rolled wrought-iron girders of I-shaped section, 12 inches deep, bent to the proper curves, and resting between joggles on cast-iron caps, supported by brick piers 1 foot 10½ inches square, 8 feet high, and about 12 feet from center to center. The foundations of the piers are carried through the bottom of the reservoir to the solid earth, and are built with two double courses of footings; the piers are further supported and connected by rings of 18-inch inverts. The inner covering arch rests on a central well-hole 8 feet in diameter, domed over; a hole 3 feet in diameter in the center gives access to the interior; a backing of puddle 1 foot thick is carried up outside the exterior arches to render them watertight. The spandrels are filled in with a layer of 1 foot of concrete and 2 feet of earth, and together with the sloping bank are covered with turf, but the crown of the arches is bare, the outside ring being formed of hollow gault bricks.

The cost of covering the reservoir was £3,153, including £464 for the ironwork. An electric gauge, supplied by the General Post Office, indicates the level of the water in the reservoir on a dial fitted in the engine house at Deptford. The rent paid by the company for this gauge is £20 per annum.

The covered reservoir at Deptford was formerly a filter bed; the dimensions at the top of the slope being 250 feet by 140 feet, and at the bottom 230 feet by 120 feet, the depth is 9 feet in the center, the bottom has a rise of 6 inches towards the sides; the bottom and sides consist of a layer of 12 inches of puddle, and of 5 inches of concrete made with 9 parts of Thames ballast to 1 part of blue

lias lime. The bottom is paved with brick laid flat in cement, and the sides with brick on edge. The filtering material consisted of a layer of rubble stone, four layers of gravel, one layer of shells, and 18 inches of Hardwich sand; the total thickness was 4 feet 3 inches. It was formerly used for filtering the water from the river Ravensbourne; but on the company abandoning this source in favor of a supply from chalk wells, it was obviously desirable that the water should be pumped into a covered reservoir, rather than on to a filter bed, and put through a process of filtration, which exposed the water to the heat of the sun, depriving it of its freshness and coolness in summer, whilst frost rendered it unnecessarily cold in winter.

As it was necessary before converting these filters into covered reservoirs to remove the filtering material, it occurred to the author's father that a great saving in expense might be effected by using the gravel and sand for a concrete covering instead of brickwork. The idea was successfully carried out by the company's workmen, aided by a couple of bricklayers for building the piers and longitudinal arched wall which supports the concrete arches. This wall is 18 inches thick, and the piers are 18 inches by 22½ inches; the distance between the piers is 12 feet, and the rise of the brick arches is 2 feet 6 inches. The concrete arches have a similar span and rise; the thickness at the crown is 10 inches, and at the haunches 20 inches. The concrete was made from the gravel and sand of the filter bed mixed in the proportion of 7 parts of ballast to 1 part of Portland cement.

There was another filter bed 160 feet long and 100 feet wide, covered at the same time in a similar manner, the same centering being used for both. The cost of covering the two reservoirs, which have a superficial area of 51,000 square feet, including the cost of centering, was £2,669. These reservoirs, which contain about 2,000,000 gallons of water, were covered in 1872. Water from the wells is pumped into them, and is then pumped into the mains for the supply of the district.

One of the reservoirs attached to the Plumstead Works, formerly used in connection with the lime-softening process, is now used as an intermediate reservoir between the lift pumps and force pumps. The covering, Bunnett's flooring, consists of two flat arches, having a rise of only 3 inches in a span of 19 feet, formed of two layers of hollow arched bricks rebated to fit into each other; the thickness of the arch is 6 inches. The arches rest in the center on a rolled joist, supported by six cast-iron columns; the outer ends of the arches are supported by angle-iron abutments in the side walls; the angle-iron abutments are each bolted to the central joists by fourteen tie-rods. The reservoir at the top is 73 feet long by 38 feet wide; the cost of the roof was £242.

The Woolwich common reservoir was built as a substitute for the old uncovered circular reservoir, constructed at the cost of the Admiralty in 1845, as it was found impossible to cover the latter without seriously deranging the supply to the district. The Government, therefore, on the application of the company, granted a site adjacent for a covered reservoir in exchange for the old reservoir. It was one of the conditions on which the site was granted that the top of the reservoir should not project above the original surface of the ground.

The foundation was excellent, the soil consisting of solid London clay. A pond occupied part of the site, but no difficulty arose in connection with it, as a drain-pipe had, in the first instance been laid at a sufficient depth to carry off rain or surface water from the excavation. The reservoir is rectangular, 200 feet long by 100 feet wide, with a depth of 12 feet of water when full. It is covered by eight arches, consisting of two rings of brickwork, having a radius of 8 feet and a rise of 2 feet, springing from seven rolled iron I girders 12 inches deep with 6-inch flanges. The skew-backs are formed of gault bricks fitted between the flanges, and the two exterior arches of three rings of brickwork, which are carried down till the springing is level with the center from which the arch is struck. They rest with three courses of footings on the side walls, which are of concrete, 3 feet thick and 5 feet 6 inches high, faced with 4½ inches of brickwork.

The wrought-iron girders rest on one hundred and five brick piers, 1 foot 10½ inches square, 12 feet 6 inches from

center to center; they are built with four courses of footings, and are also supported by a series of brick inverts, running across the reservoir, which serve as struts for the side walls; the inverts are only 18 inches wide and rest on two courses of footings. The end walls are formed of concrete, faced with 4½ inches of brickwork in 8 bays, having a radius of 7 feet, and a batter of 3 inches in 10 feet, and are 3 feet thick; the apices of the curves consist of brick piers 3 feet square, set diagonally; the four corners of the reservoir are supported by T-shaped brick piers 5 feet 3 inches by 3 feet, with projections 2 feet 7½ inches by 9 inches. The floor consists of 6 inches of concrete laid on 6 inches of puddle. The surface is curved to correspond with the sweep of the cross inverts, and has a fall of three inches towards the western end. The whole of the brickwork is of the best hard stocks, laid in cement mortar of 3 parts of sand to one part of Portland cement. The concrete is formed of six parts of Thames ballast to one part of Portland cement.

The reservoir is connected with the company's mains by two 18-inch pipes built in the wall of the western end; the sluice cocks are in a pit outside the reservoir; a 12-inch overflow pipe is built into the wall at high-water level. There is also a drain pipe with a 4-inch scouring cock for use in cleaning out the reservoir.

The interior is reached by two manhole doors with an iron ladder; small air shafts are fixed for ventilation, and a Richmond's float-gauge indicates the height of water.

The reservoir contains 1,500,000 gallons; it was designed by the author's father, and was executed by Messrs. J. Aird & Son, at a total cost of £5,500.

In 1874 a covered reservoir was built on Telegraph Hill, New Cross, under the author's direction. It is 200 feet long by 100 feet wide; the depth of water is 14 feet, and the top-water line is 163 feet above ordnance datum. The construction is almost identical with that of the Woolwich Common reservoir, but in this instance the wrought-iron girders were omitted, and their place supplied by brick arches springing from the piers, similar to the Farnborough reservoir.

The reservoir is not entirely below the level of the ground, the top of the embankment being from 6 feet to 9 feet above the original surface of the land. The foundation is excellent, the excavation being in the London clay, which, however, when exposed, forms a bad embankment. The banks have, therefore, a slope of 2½ to 1. The concrete was made of 1 part of Portland cement, to 4 parts of river ballast and 2 parts of burnt ballast.

In constructing this reservoir it was found that the thrust of the longitudinal arches tended to force back the top of the end walls, which were only supported by the made earth; at the same time the wall turned on the edge of the solid ground as a center, and the toe was thrust forward into the reservoir. The movement was so slight as to be barely perceptible, and was promptly arrested by the introduction of inverts to support the toe of the wall. The reservoir holds about 1,750,000 gallons. The cost, including the boundary wall, was £5,280.

In 1877, the Kent Waterworks Company, at the invitation of the Bromley Rural Sanitary Authority, applied to Parliament for powers to supply water to the Cray Valley and to other parishes, namely, the parishes of Stone, Swanscombe, Darenth, Wilmington, Sutton at Hone, Farningham, Eynsford, Foot's Cray, North Cray, St. Paul's Cray, St. Mary's Cray, Orpington, Chelsfield, Farnborough, Keston, Hayes and West Wickham; the Company also applied for parliamentary power over a portion of the parish of Beckenham already supplied by them, in which their Shortlands pumping station is situated, it being a few yards beyond their former water limit.

The author was directed to prepare plans showing the works required for the supply of the district. These included a service-reservoir, for which he selected a site on Cowlass Hill, in the parish of Farnborough, about ½ mile south-west of the high road to Sevenoaks and Tunbridge, having an elevation of 445 above ordnance datum, sufficiently high to command all but a few isolated points.

The plot of land is an irregular oblong, approximately 400 feet long by 220 feet wide; the levels vary from 428 feet above ordnance datum in the north-west

corner to 445 feet, the highest point towards the south east. The geological formation consists of the Lower Eocene Beds of the Tertiary Series, which rise up from the London Basin and terminate at this point in a steep escarpment overlying the Chalk.

The present reservoir occupies about one-half the land, leaving sufficient for another reservoir should it eventually be required; it is square in plan, the length of each side being 125 feet; the depth of water is 15 feet, the highest water-level is 440 feet above ordnance datum, and it contains about 1,400,000 gallons.

One of the principal difficulties attending the construction of the reservoir was the necessity of making a proper road up to the site, which is 900 yards from the high road; the existing road over heavy clay land being little more than a cart track; while the ascent about 90 feet, is in some parts rather steep. This, and the fact that all the materials had to be carted a distance of over 2 miles from the Orpington Station on the South-Eastern Railway, added considerably to the cost of construction, which was £8,207.

Before commencing the reservoir a 14-inch pipe was laid along the line of pipe No. 1 in communication with the Shortlands pumping station, in order that water should be on the spot for the use of the contractor; and at the same time a 12-inch stoneware pipe was laid in the same track, as far as a brook which crosses the line of pipe, to act as a drain pipe whilst the work was in process, and as an overflow and emptying pipe for the reservoir. The laying of these pipes had been completed and did not form part of the contract.

The contractors, Messrs. J. Aird and Son, at once proceeded to lay down a line of tramway from the high road to the reservoir for the purpose of bringing the materials on the ground. The reservoir was staked out and the work commenced on the 6th of May, 1879. A trench was in the first instance excavated, in which the side walls of the reservoir were to be built; it was 8 feet 3 inches wide with an average depth of 11 feet 6 inches, and was closely timbered. The nature of the soil was remarkable; that in the eastern trench consisted of bright Thanet Sand, which extended for a short distance along the north and south trenches; to the west of this succeeded gravelly clay, with shelly clay and good yellow clay above, blue clay with veins of lignite below; the bottom of the trench on the western side was entirely in peat or lignite, which also returned about half way round the northern and southern trenches, the whole of the stratification being of a most irregular character. As the lignite was too thick to be dug out, and was fairly solid when not disturbed or exposed to the weather, it was determined to build the wall upon it, but to make the foundation somewhat wider than was at first intended. The whole of the bottom of the trench was therefore covered with puddle varying from 9 to 12 inches thick, made of the clay excavated from the reservoir. When tempered and passed through a pug mill it made first-rate puddle. A space of 12 inches was left on the external side of the trench for puddle backing, and the remainder of the trench was filled to a depth of 18 inches with concrete formed of 6 parts of clean Thames ballast to 1 part of Portland cement. The concreting was commenced on the 26th of June.

On this footing, which was 7 feet 3 inches wide, the side walls were built of $4\frac{1}{2}$-inch brickwork, 1 foot high, to form the inside face of the reservoir, with a layer of concrete behind, 4 feet $1\frac{1}{2}$ inch wide and 1 foot thick, thus making the thickness of the wall 4 feet 6 inches. The construction was thus proceeded with in layers 1 foot at a time, with a header for every fourth course of brickwork to tie it into the concrete. The top of the wall was reached at 6 feet 6 inches from the footing or 8 feet from the puddle.

Meantime, three cast-iron pipes were laid in separate trenches under the western wall. One pipe in connection with the 14-inch pipe, line No. 1, already inserted, the second in connection with the overflow and emptying pipe, the third in reserve ready to be connected with the line of main No. 2, if it should eventually be required. These trenches were filled with well-rammed puddle, and covered with York landings, 6 feet square and 6 inches thick, where the pipes passed under the side wall.

The outside wall having been brought to springing height, the timber at the back of the wall was withdrawn, and the

puddle backing rammed in. It was intended by the author that the wall should be temporarily strutted against the dumpling of earth in the interior, till permanently supported by the cross inverts from east to west, and by the foundations and inverts of the bull's-eyes at the northern and southern ends; but as it would have entailed some extra excavations and timbering, the contractors delayed this part of the work and proceeded with the excavation of the dumpling, some of the earth being used to form the banks of the reservoir, and the remainder being wheeled to spoil on the Company's surplus land.

The earth had been removed down to the level of the 18-inch concrete footing all along the eastern side and northern end of the reservoir without any ill effect, and the cross inverts were being commenced, when the western side wall, from which the earth was being removed, cracked, on the 26th of August, and bulged forward about 2½ inches in the center. Struts were at once put in, and about half of the cross inverts were completed, when, after heavy rain on the 14th of September, the western wall, with the exception of about 30 feet at the north end, slid bodily forward some 5 feet into the reservoir, doubling up three of the cross inverts which should have supported it. The contractors thereupon proceeded to break up the concrete wall, which proved to be of very good quality, and to excavate the earth which had fallen in behind it. When the debris had been removed, a small land-spring was found at the back of the wall; this spring and the trenches which had been cut through the bank for the purpose of laying the pipes under the wall, no doubt, contributed to its destruction.

Although the puddle under the wall had not shifted, it was thought desirable to remove it, and to excavate the ground to an additional depth of 18 inches. The soil was still peat and lignite, on which a layer of 9 inches of puddle was placed, the thickness of the footing of the concrete wall being increased from 18 inches to 3 feet. The foundations of the inverts which had been upset were similarly increased, and the inverts throughout were strengthened by making them of three rings instead of two rings of brickwork.

Before filling in at the back of the reinstated wall, a stoneware drain pipe was laid to collect the land-spring, and lead it into the 12-inch drain-pipe. Seeing that this new piece of wall was without a backing of solid earth, the author thought it desirable to strut the wall by seven cast-iron columns 12 feet long, which happened to be in hand, with one end against the solid earth, and the other against the back of the wall behind each invert, to prevent the wall being forced outward by the internal pressure of the water, and the thrust of the covering arches.

The footings for the end bull's-eyes and cross inverts are built on concrete foundations, 4 feet wide and 9 inches thick, on a 9-inch layer of puddle deposited in trenches 18 inches below the floor of the reservoir, to prevent the puddle being squeezed out from under the concrete. The central cross inverts, which are 12 feet 6 inches from center to center, are 1 foot 10½ inches wide, formed of three rings of brickwork supporting brick piers 1 foot 10½ inches square, 12 feet 6 inches from center to center, and 10 feet high. From the top of these spring the arches of the longitudinal wall carrying the covering arches; this wall is 18 inches thick; the arches are formed of two rings of brickwork, having a radius of 8 feet and a rise of 2 feet; 18 inches above the soffit of these arches spring the covering arches, resting on concrete skew-backs. These are built of two rings of brickwork tied together by the insertion of headers at convenient distances; they have a radius of 8 feet and a rise of 2 feet, the spandrels being filled in with a bed of 15 inches of concrete. The external arches, which carry the thrust of the covering arches down to the concrete side walls, consist of three rings of brickwork, and have a radius of 9 feet 6 inches. These arches have been backed up on the outside with concrete, which not only stiffens them but forms a better surface for the puddle to rest against. The puddle backing 1 foot thick is carried 1 foot above the top water-line.

The north and south walls also have covering arches resting on the concrete walls, which the author believes to be an unusual form of construction. To support these end arches and strengthen the work, he has interposed an arched cross

wall of 2 feet 3 inches between them and the covering arches, and has further stiffened the structure by bull's eyes to take the thrust of the longitudinal arches, and at the same time to act as struts to prevent the concrete wall being forced inward by external pressure. The bull's-eyes are 12 feet 6 inches in diameter, 2 feet 3 inches thick, and are formed of three rings of brickwork, which is toothed into the brickwork of the covering arch, the whole being tied together by two stout hoop-iron bands which extend along each of the longitudinal walls from one end of the reservoir to the other. The floor of the reservoir, the surface of which is level with the inverts, is slightly undulating, and has a fall to the center for drainage. It is formed of 9 inches of concrete laid on 9 inches of puddle; a 9-inch trench was dug down to the puddle beneath the foundations, and a proper connection made between the two layers of puddle The surface of the reservoir is covered with earth to the depth of 1 foot above the crown of the arches, and is sown with grass. The side slopes have an inclination of $2\frac{1}{2}$ to 1; at the north-east corner, the top of the bank is 14 feet above the foot of the slope; an ordinary post and rail fence round the Company's land was included in the contract.

The sluice cocks, on the 14-inch main and on the 12-inch emptying pipes, are fixed in circular pits inside the reservoir; at the back of the emptying cock a branch pipe is carried up, terminating in a bell mouth at the top water-line, which acts as an overflow and allows surplus water to escape. The bricks used were red, wire-cut gault bricks from Dunton Green, laid in Portland cement mortar, 3 parts of sand to 1 part of cement; the sand was partly Thames sand, but chiefly pit sand from Dartford Heath. The reservoir is fitted with twenty-four air pipes for ventilation, access to the interior is by two manholes formed in the covering arches, closed by two heavy cast-iron doors and frames resting on York landings. The descent to the bottom of the reservoir is by a wrought-iron ladder. Severe frosts, during the months of December and January, considerably delayed the completion of the work, which was finished on the 7th of February, 1880.

The Hornsey Wood Reservoir was built for the East London Waterworks in 1868, from the designs and under the direction of Mr. Charles Greaves, M. Inst. C. E., by Messrs. Aird & Son. The internal dimensions are 454 feet 6 inches by 186 feet; with the maximum depth of water, 11 feet 6 inches, it contains about 5,000,000 gallons. The site is on the London clay, the earthwork being for the most part excavation, the pot-water-line is wholly below the original surface of the ground.

The side and end walls are of brickwork in cement 18 feet high, built on a foundation of concrete 5 feet 6 inches wide and one foot thick; the internal faces of the walls are vertical, but the thickness diminishes at the back in half-brick steps from 3 feet 9 inches at the base to 1 foot $10\frac{1}{2}$ inches at the top; the walls have a backing of concrete parallel with the interior face of the wall and 4 feet 6 inches from it.

The roof consists of fifteen vaults springing from the sides, and running longitudinally from end to end of the reservoir; the span of the arches is 11 feet 4 inches, and the rise 2 feet 10 inches; they are formed of two rings of brickwork, and the spandrels between the arches are filled with concrete to the height of 2 feet 6 inches. The vaulting is supported by fourteen longitudinal walls 18 inches thick, with footings 3 feet wide resting on the solid earth; these walls are pierced with twenty-seven arched openings, 13 feet 6 inches wide, with semicircular soffits; the arches are formed of three rings of brickwork, the inverts have a versed sine of 18 inches, and the height of the openings from the bottom of the invert to the soffit of the arches is 9 feet 9 inches; the piers between these openings, which are 3 feet $4\frac{1}{2}$ inches wide, are stiffened by 18-inch buttresses, which diminish from one and a-half brick at the base to one-half brick at the top.

The floor consists of brick inverts 9 inches thick, having an internal radius of 11 feet 1 inch, resting on concrete; there is an extra ring of brickwork 18 inches wide between each of the piers. The height from the springing of the inverts to the springing covering arches is 12 feet 6 inches. The reservoir is covered

with earth to the depth of 2 feet 6 inches above the crown of the arches.

The Haggar Lane Reservoir was recently constructed for the East London Waterworks Company, from the designs and under the direction of the late Mr. George Seaton, M. Inst. C. E.

The earthwork consists one-half of excavation and the other half of embankment. The top water-line, which is 167.50 feet above ordnance datum, ranges from 8 feet 6 inches to 6 feet 6 inches above the original surface of the land. The dimensions of the work, to the outside of the puddle walls, are 191 feet 6 inches by 121 feet 6 inches, the inside dimensions being 182 feet by 112 feet. The exterior walls are built in curved bays, 18 inches thick, but the footings, which rest on 9 inches of concrete, are straight on plan. The bays have a versed sine of 18 inches, and are carried to the top in the end walls, but in the side walls the brickwork is corbelled over to form a straight skew-back for the covering arches. The brickwork is backed with concrete, which fills in the spandrels, and is 3 inches thick at the thinnest place; the concrete has a straight exterior face, between which and the earthwork there is a layer of 18 inches of puddle. The floor is formed of brick inverts 9 inches thick; the inverts have a span of 15 feet, a rise of 2 feet, and rest on concrete, which has a minimum thickness of 6 inches; beneath the concrete there is a layer of puddle 18 inches thick. The vaulting is supported by six 14-inch longitudinal walls, strutted and stiffened by six 14-inch cross walls; these walls divide the reservoir into forty-nine sections, each measuring 25 feet by 15 feet. In order to permit the water to flow through these sections, the side walls of each section are pierced with circular openings 8 feet 3 inches in diameter, and the cross walls with circular openings 6 feet in diameter. The longitudinal walls rest with three courses of footings on 9 inches of concrete; at the top they are thickened to 18 inches to form skew-backs for the springing of the vaulting; the cross walls are built on the inverts to the height of 7 feet 6 inches; for 7 feet in the center the top of the wall is level, whence the brickwork slopes up to the springing of the covering arches. The vaulting, which has a span of 14 feet 3 inches and a rise of 3 feet 9 inches, is formed of two rings of brickwork; the spandrels are filled up with 18 inches of brickwork, and 18 inches of concrete; the arches are covered with 2 feet of earth. The banks of the reservoir have a slope of $2\frac{1}{2}$ to 1.

The vault, next the side of the reservoir from which the water flows through the pipe to the engine, is an exception to the other longitudinal walls; it has only one circular opening at the further end, the object being to induce a circulation of water through the reservoir. This wall is lightened by 9-inch panelling. There is a recess in the floor 2 feet 6 inches wide, with openings under the longitudinal walls to collect the drainage, and lead it to the pipe at the corner of the reservoir. The maximum depth of water is 14 feet from the bottom of the invert; the reservoir contains about 1,500,000 gallons.

The author has been favored by Mr. Alexander Fraser, M. Inst. C. E, the Engineer of the Grand Junction Waterworks Company, with drawings of the Kilburn and Hampton reservoirs.

The Kilburn reservoir is 300 feet long by 175 feet wide; with the depth of water of 20 feet it contains 6,000,000 gallons. It is excavated to a depth of about 14 feet in the London clay; the embankment rises about 13 feet above the original surface of the ground, which is nearly level; the side walls rest on a concrete foundation 5 feet wide and 2 feet thick, and are built of brickwork 1 foot $10\frac{1}{2}$ inches thick, in curved bays 20 feet across, having a radius of 18 feet and a versed sine of 18 inches. The spandrels are filled in with concrete so that the back of the wall is straight; behind the wall is puddle backing 3 feet thick. The brick piers carrying the roof are cruciform in plan, 4 feet 6 inches across by 18 inches thick; they are built with four double courses of footings, and rest on blocks of concrete 6 feet square and 2 feet thick, sunk 4 feet below the level of the floor; the piers are 21 feet 6 inches from center to center. At 15 feet from the floor-line the arches which support the cross walls spring from these piers; they have a span of 17 feet, a rise of 3 feet, and are 18 inches thick. The covering arches spring from the cross walls at 20 feet above the floor-line; they have a span of 20 feet, with a rise

of 4 feet, and are formed of two rings of brickwork. They are stiffened internally by an arched rib of 18 inches square, springing from each of the cruciform piers. Where the arches rest on the end walls the brickwork of the curved bays is corbelled out to a straight skew-back for the arches to spring from.

The outer wall is supported against the pressure of the external earth by buttresses between each of the curved bays, which extend as far as the foot of the first of the cruciform piers; they are 1 foot 10½ inches thick, and are built with four double courses of footings on a concrete base 6 feet wide and 2 feet thick. The floor is concrete 12 inches thick. The reservoir is covered with earth to the depth of 1 foot 6 inches above the crown of the arches. The cost of the reservoir, which was built in 1872 by Messrs Aird and Son, was about £23,000. The brickwork is very similar to that of the Nunhead reservoirs, except that in the latter, bull's-eyes are used for the support of the external walls instead of buttresses. The earthwork, however, is of an entirely different character, the Nunhead reservoirs being built on sloping ground.

The reservoir at Hampton is 240 feet long and 155 feet wide; the maximum depth of water is 12 feet, and it contains 2,750,000 gallons. It is built entirely of concrete; the foundation rests on blue clay, above which the soil consists of excellent clean sharp ballast, admirably suited for concrete. The side walls are 6 feet thick at the base, 3 feet thick at the top, and 14 feet high; the back of the walls is vertical, the whole of the latter being on the internal face.

The walls are backed with 18 inches of puddle. The piers are 12 feet from center to center, and 13 feet high; they are taper, being 2 feet square at the base and 18 inches square at the top; they are capped with York stone, on which rest wrought-iron rolled joists 8 inches deep, with 4-inch flanges; the joists are tied with ¾-inch galvanized wrought-iron rods 6 feet apart, which fasten the whole of the roof together, and relieve the side walls from any outward thrust.

The roof consists of arches, with a span of 12 feet and a rise of 2 feet 6 inches, springing from the wrought-iron joists; the concrete is 9 inches thick at the crown and 18 inches thick at the haunches. The concrete is covered with 6 inches of earth. The floor is formed of concrete 1 foot thick. The reservoir is not rendered internally; but the surface of the concrete was smoothed over with cement mortar as the moulds were removed. The concrete was made from ballast dug out of the excavation, from which all stones that would not pass through a 1½-inch sieve were removed before mixing, or broken to a proper size. The proportion was 6 measures of ballast to 1 measure of Portland cement. This reservoir is entirely below the original surface of the ground. The concrete in the piers takes some time to set sufficiently hard to be loaded, and on this account, if time is an object, it is in Mr. Fraser's opinion, questionable whether brickwork would not be preferable for the piers, although concrete is somewhat cheaper. The reservoir was built in 1880, at a cost of about £8,000.

The Burton-on-Trent reservoir has been constructed for the South Staffordshire Waterworks Company from the designs and under the direction of Mr. W. Vawdrey, M. Inst. C. E.

It is built on a hill to the south of the town on stiff clay soil; about one-half of the earthwork consists of excavation and one-half of embankment. It is rectangular on plan, covered by brick arches, springing from cast-iron girders, supported on cast-iron columns. The dimensions at the floor-line are 224 feet 6 inches by 145 feet 10 inches, and at the top 229 feet 6 inches by 150 feet 10 inches; the depth of water is 21 feet.

The external walls are of concrete faced with brindled Stafford brickwork built in Portland cement. On plan the brick walls are formed of a series of brick piers with curved bays between them; the distance between the centers of the piers in the side walls is 13 feet 6 inches, and in the end wall 15 feet. The versed sine of the curves is 1 foot; the brickwork, which is built with every alternate four courses, 14 inches and 9 inches thick, has a batter of 1 in 8; it is carried down 3 feet 6 inches below the floor, and rests with four courses of footings on a foundation of 18 inches of concrete. The back of the concrete wall is straight in plan, and is carried down vertically with the exception of a 6-inch set-off at the junc-

tion of the solid ground and the embankment. The total height of the wall is 25 feet 6 inches; the minimum thickness of the concrete and brick in the center of the bays is 3 feet 1½ inch at the top, and 6 feet 7½ inches at the bottom; the base of the concrete, which extends under the footings of the brickwork, is 11 feet wide; the concrete wall is backed with, and rests on, puddle 12 inches thick; the floor is a bed of 10 inches of concrete, on 18 inches of puddle. There are one hundred and forty-four hollow columns, which rest on stone blocks 3 feet square by 15 inches thick. These stones project 3 inches above the level of the floor, and are supported on blocks of concrete 5 feet square by two feet thick, below which there is a 12-inch layer of puddle.

The columns are cylindrical, of cast iron, 10 inches in external diameter, and 1 inch thick; they are made in two pieces, each piece being 10 feet long, bolted together in the center. The girders, which are bolted to the top flanges of the columns, are 15 feet long, I shaped in section, the depth at the ends being 10 inches, and in the center 20 inches; the bottom and top flanges are of equal width throughout, viz., 8 inches and 16 inches; the thickness of the top flange is 1¼ inch, of the bottom flange 1½ inch, and of the web 1 inch. Each girder is bolted at the end to the one next it; the girders are tied together by two 1¼-inch galvanized tie-bars to each length of girder, and the sidewalls are thus relieved of any thrust from the roofing.

The covering arches have a span of 13 feet 6 inches and a rise of 18 inches, and are formed of two rings of brickwork in cement. The spandrels of the arches are filled in with concrete and the concrete is covered with asphalt to prevent the percolation of rain-water through the roof. The rain-water is collected in drains which discharge at each side of the reservoir. The roof is covered with about 1 foot of soil and turfed over. The parapet which retains this covering is curved to a height just level with the soil over the arches; it rises 3 feet above the top of the earthwork, and is neatly formed of blue bricks with panels of blue and red chequer work. The top of the bank is about 10 feet wide, with a slope of 4 to 1 to the original surface. The reservoir contains about 4,000,000 gallons, and cost about £15,000.

Covered Reservoirs in Germany and Austria.

The author had an opportunity, during a short tour with Mr. Alexander Aird, Assoc. Inst. C. E., of Berlin, of seeing something of the waterworks of the principal cities of Germany. He therefore proposes to give some description of their reservoirs, together with a few incidental notes on other points.

The reservoirs of the Berlin Waterworks at Charlottenburg are built of brick, and are very similar in construction to the Kilburn reservoir, cruciform piers being used; but the sidewalls are straight on plan, and wholly of brick, 10 feet thick at the base, and battering to 4 feet at the top. The span of the arches is 20 feet, the depth of the water 14 feet 9 inches, and the contents of each reservoir are 2,541,000 gallons.

Instead of buttresses, bulls'-eyes are built between the side walls and the first row of piers, the spaces between the bulls'-eyes being arched over; consequently, the arches in front of the end walls are at right angles to the main covering arches across the reservoir, and form groynes where vaults intersect. By this arrangement only four abutments, one abutment for each of the four corner 20-feet compartments, are necessary.

The site of the reservoirs is very fine, loose sand, so absorbent that it was necessary to spread bitumenized paper over the bottom of the excavation before concrete could be laid on it. The floor consists, first, of bitumenized paper; secondly, of a layer of 15 inches of concrete; thirdly, of 15 inches of puddle; fourthly, of 6 inches of concrete, the surface of which is rendered. The reservoirs are fitted with an electric water-level indicator, with an automatic graphic recorder, by Messrs. Hipp & Co., Neuchatel, Switzerland, of which Mr. Henry Gill, M. Inst. C. E., the chief engineer, has favored the author with the following description:

"The Charlottenburg reservoirs are distant from Tegel about 7,500 yards, and two wires are laid between the respective engine houses; that at Charlottenburg contains the battery. The float in the reservoir at each rise or fall of 4 inches completes the circuit, and actuates the

registers at the engine-houses at Charlottenburg and Tegel. At Tegel an electric clock drives a drum which revolves once in twenty-four hours; on this drum an endless roll of paper is wound; in front of this horizontal paper-covered drum runs a small trolly carrying an ink-fed style or pointer. The trolly is caused to advance or recede by the currents produced by each contact made by the rise and fall of the float in the reservoir, and as the style is in contact with the paper on the revolving drum, a diagram is traced which records the height of water in the reservoir at any given time. Its accuracy is checked once a day by Morse's dot and dash telegraph. The apparatus is found to work very satisfactorily. The water which is pumped into the reservoir from Tegel is derived from a series of wells, sunk near the margin of the Tegel lake, which yields an abundant supply of water, (10,000,000 gals. per diem); but unfortunately the water contains filaments of an alga (*Crenothrix Polyspora*), which, on passing through the iron water mains, is thrown down in the form of a brown deposit. This accumulates in the reservoirs and water mains to such an extent that the water as delivered to the consumers is frequently much discolored. It is remarkable that it was not till the works had been in action for six months that any sign of the alga made its appearance."

Mr. Gill has favored the author with drawings of the Berlin covered filters; they are covered reservoirs, which only differ from others in containing filtering material.

Mr. Gill makes the following observations on the climate of Berlin: "Frost usually sets in here about the 15th of November; if it lasts about ten days, the average duration of the first attack, the earth is frozen to the depth of 12 inches, and open reservoirs and filters are covered with ice from 4 inches to 6 inches thick; then there comes a relaxation of the grip of winter for three or four weeks, so that during the day the thermometer rises to 45° or 50° Fahrenheit, but falls to freezing point at night. The days are too short, however, for the mid-day temperature to have much effect upon the frozen ground or the sheets of ice on the reservoirs, and these remain increasing in thickness to about the middle or end of February; but even when, say about the end of February, the ice has become thin, and early in March has disappeared, the night frosts prevailing till the end of March prevent the laying dry and cleansing of the filters."

It is in Berlin seldom possible to cleanse an uncovered filter in the period from the 15th of November to the 15th of March. It is therefore indispensable, if the necessity of giving unfiltered water is to be avoided, to construct filters so that they can be cleansed even during the prevalence of the severest frost. Hence the vaulted filters of the Berlin Waterworks, which have been copied in the Magdeburg Waterworks. Each division of the filter measures 175 feet by 125 feet, and is divided into sections 11 feet 6 inches square by the piers, which are two bricks or 20 inches square. These sections are domed over with Bohemian vaulting (*Bomische Kappen*), in the apex of which there is an opening for a window. Each dome which is a segment of a hollow sphere, rests on longitudinal and transverse arched ribs springing from the piers referred to above. The arched ribs are kept low, so that there is only just room for a man to wheel a barrow under the center, which prevents the barrow striking against the piers. The size of the window is so regulated that the surface of sand in every separate section gets a direct ray of light. This is necessary in cleansing the filter. The window is covered loosely with a sheet of glass ½ inch thick, and during severe frosts a wooden shutter is laid over the glass; in summer the glass and shutter lie off at the side. The barrow road, for which a special inclined archway is built, consists simply of movable planks resting on supports; when not in use the planks are laid on brackets above the water-line.

The foundation of this filter is a layer of 18 inches of puddle; but the base of the side walls, and the inverts which support the piers, rest on gravel puddle 6 feet 6 inches wide under the side walls, and 5 feet 4 inches wide under the inverts. It is made as follows: First, a layer of 6 inches of puddle, then of 3 inches of metal or broken stone as used for macadamized roads; this is rammed into the clay till the clay rises to the surface; similar layers succeed, each of puddle and metal, till the required thickness

is obtained, the stone being thoroughly rammed into the clay. The floor consists of 9 inches of concrete rendered. The walls are of brick 3 feet 3 inches thick and 11 feet high. The water-line is 8 feet above the floor, which is also the springing-line for the arched ribs. The roof of the filter is covered with 2 feet of earth.

These filters are rather expensive, the cost at Berlin, including valve-chambers, valve-regulators, &c., is about 90*s.* per square meter, but the covering is indispensable.

The reservoir at Breslau consists of two wrought-iron tanks fixed inside a water-tower 130 feet above the ground. The tower is built of brick, square on plan with cross walls to stiffen the structure. These divide the building into four compartments, which are utilized as engine houses, and contain a pair of single-acting Cornish pumping engines and a vertical direct-acting double cylinder fly-wheel pumping engine; there is still vacant space for another engine: The wrought-iron tanks are each 84 feet long by 41 feet wide and 20 feet deep, containing about 900,000 gallons. They rest on expansion plates, so that they are free to expand or contract without affecting the brickwork. The tower which entirely encloses the tanks is covered with a slate roof, and presents a bold and massive appearance. It stands on the bank of the river Oder, from which the city is supplied with filtered water.

The reservoirs of the Vienna Waterworks are computed to contain about 21,000,000 gallons, which at the time when the author visited the work (October) was equal to three days' consumption. This is sufficient to permit of repairs being made to the aqueduct without interfering with the water-supply to the city; the emptying and filling of the aqueduct occupies about thirty-six hours, leaving thirty-six hours for the actual repairs. The aqueduct is about 55 miles in length, and eight hours are occupied in the water flowing from the source at Kaiserbrunnen to Vienna. The quantity of water supplied by the two springs which feed the aqueduct, the Kaiserbrunnen and the Stixenstein, varies from 145,000 cubic meters per diem in summer to less than 29,000 cubic meters in winter, when the snow and other sources from which these springs are fed are frost bound. This quantity is less than half the estimated water-supply. In order to supplement the supply, wells have been sunk in the gravel beds of the valley of the Schwarza at Pottschach, from which 17,000 cubic meters per diem are pumped into the aqueduct during winter; these supplemental works were designed and executed by Baron Schwarza and Mr. Aird's firm.

The author is indebted to the Oberingenieur Mihatsch for the particulars of the Schmelz reservoir. It is 347 feet square, with a depth of 12 feet of water, and contains about 8,000,000 gallons. The foundation is cut out of the solid rock. The side walls are of brick 5 feet thick; the piers are of masonry 3 feet 6 inches square on brick footings; the cross vaulted roofs rest on these piers, the span of the vaulting being about 22 feet. The floor consists of one course of brickwork laid flat on the surface of the rock, over which is a layer of concrete. The bottom and sides are rendered with Portland cement. Great care is taken to ensure circulation of water through the reservoir, it being considered very undesirable that any portion of the water should be allowed to become stagnant; hence there are division walls connecting the piers.

The new waterworks at Munich, which were in course of construction by Mr. A. Aird's firm, comprise a high-level reservoir about 7 miles from that city, and an aqueduct or conduit about 19 miles in length from the springs in the Mangfallthal to the reservoir. These springs issue from the west side of the valley about half way up the slope, where an extensive bed of porous limestone-gravel rests on a bed of impervious clay, and are at a sufficient elevation to supply Munich by gravitation.

The reservoir is divided into two compartments by a division wall; each compartment is 272 feet square, with a depth of water, when full, of 10 feet, the contents altogether being about 8,800,000 gallons. The bottom is 10 feet 6 inches below the original surface of the ground; the soil is limestone gravel, consisting for the most part of smooth water-washed pebbles. The side walls are of concrete 3 feet 8 inches thick and 7 feet 6 inches high, built in a trench 6 feet 6 inches

wide; these walls have a stepped toe or footing on the inside, which not only gives a wider foundation, but is useful in breaking the joint with the concrete floor. The floor itself has a uniform thickness of 2 feet over the whole area of the excavation, the piers and division wall being built upon it. The end walls on which the covering arches rest are carried up in brickwork to the height of 3 feet 10 inches above the concrete, diminishing from 30 inches at the base to 15 inches at the top, which corresponds with the level of the water in the reservoir when full. The piers supporting the cross arches are also of brick 26 inches by 20 inches (German bricks are somewhat longer and wider than English bricks). The height from the floor to the springing is 4 feet 3 inches; the cross arches for supporting the vaulting are formed of three rows of brickwork, with a span of 10 feet 2 inches and a rise of 30 inches. The vaulting is semi-circular and has a span of 10 feet 3 inches, the springing being 7 feet 8 inches above the floor; it is formed with one ring of brickwork about 5 inches thick. The spandrels are filled in with concrete to the height of 3 feet, and the ends of the vaults are closed with brickwork, battering from 3 feet to 15 inches, built on the concrete wall. The division wall between the two compartments of the reservoir is of brickwork to the level of the springing of the vaulting, being 4 feet 10 inches thick at the base and 3 feet at the top; the spandrel between the two vaults which rest on it is filled in with concrete to the height of 2 feet 8 inches. The crowns of the arches are covered with earth to the depth of 3 feet 9 inches; and the banks of the reservoir have a slope of 1½ to 1.

The concrete used in the construction of the above is made of 5 parts of washed and screened gravel from the excavation (all large stones being broken), 1 part of washed siliceous sand, brought from a distance, and 1 part of Portland cement. The sides and bottom of the reservoir are rendered in the following manner: As soon as the moulds have been withdrawn from the concrete after it has set, the surface is rendered with cement mortar made of 1 part of Portland cement to 1 of sand, only just sufficient mortar being used to give a smooth face to the work; it is then coated with a film of neat cement, and rubbed with irons till it takes a high polish. The finished work rings like solid marble.

The inlet and outlet pipes are built into the concrete walls. The conduit from the Mangfallthal terminates in a 29½-inch pipe. There is a double line of mains from the reservoir to the city, each line of pipes being 27½ inches in diameter.

Frankfort-on-the-Maine is supplied with water from springs in the Vogelsberg and Spessart mountains, distant about 40 miles from the city. The water from the springs flows through an aqueduct by gravitation to a high-level reservoir in the Friedberger warte, which contains 37,500 cubic meters or 8,500,000 gallons.

The reservoir consists of three compartments, the longest of which is a recent addition; an arched gangway is formed on the center division wall, which extends from one end of the reservoir to the other. The two old compartments consist of sixteen vaults, with alternate openings in the cross walls, which cause the water to flow in a zigzag manner from one end of the compartment to the other, the object being, as at Vienna, to ensure thorough circulation of the water. The vaulting has a span of about 15 feet, and is formed with four rings of brickwork. The depth of water in the reservoir, when full, is about 12 feet.

The water from these mountain springs is excellent in quality, but the quantity is far below the requirements of the city, especially in summer, when it is necessary to shut off the water from the city at noon to accumulate sufficient in the reservoir for the next morning's consumption.

The reservoir at Darmstadt is built of brick. The foundations only are below the original surface of the ground. It consists of two compartments, each 80 feet by 72 feet, with a depth of water of 13 feet. The bottom is concrete, 20 inches thick, overlaid by 9 inches of brickwork, the surface of which is rendered with cement mortar. The side walls are 8 feet thick at the base and 4 feet thick at the top. The piers of the cross arches for supporting the vaulting are 6 feet 6 inches wide and 25 inches thick; the arches have a span of 13 feet

1½ inch, and a radius of 10 feet. The vaulting is semicircular, with a span of 13 feet 1½ inch; the springing is 11 feet 8 inches from the floor, and is formed of two rings of brickwork; the division wall between the two compartments is 6 feet 6 inches thick; the spandrels of the vaulting are filled up with concrete. The reservoir is covered with earth to the depth of 3 feet 3 inches above the crown of the arches; the banks, which are of sandy soil, have a slope of 1½ to 1. The inlet and outlet pipes are so arranged that the water flows in at the top of the reservoir, but passes out through self-acting valves from the bottom. The reservoir is fitted with a ball-float, connected by a wire to the pumping station; when the reservoir is full an electric bell rings in the engine-house; there is also a communication between the reservoir and engine-house by means of a telephone. The cost of this reservoir has been 168,000 marks. It holds about 900,000 gallons.

The water with which Darmstadt is supplied is obtained frem six tube wells, about 16 inches in diameter, driven to a depth of from 150 feet to 200 feet in the sandy plain between the river Rhine and the Odenwald Mountains at Griesheim, about 5 miles from Darmstadt. The general character of the sand is too fine to yield much water, but it is traversed by permeable veins of coarse sand and fine gravel, which afford an ample supply. The normal water level is 10 feet below the surface of the ground. The engine pumps direct from the wells into the mains, the suction-pipe from the pump having branches which dip into each of the six wells; when pumping the maximum quantity required for the town, 500,000 gallons per diem, the water in the tube-wells is depressed 11 feet, but in testing the yield of the wells double the quantity has been obtained.

The project for the supply of Darmstadt was submitted to the Town Council by Mr. A. Aird's firm, in 1874, who called in an engineer to supervise the execution of the work. The latter, however, instead of so doing, persuaded the Town Council to carry out a project of his own, and instead of tube-wells, substituted a well 26 feet in diameter, which he sank to a depth of 105 feet, by the pneumatic system; but the large well only yielded one-tenth of the required supply. Mr. A. Aird's firm were thereupon applied to, and successfully carried out their original scheme.

The covered reservoir at Cologne is erected on a tower in the center of the city, about 100 feet above the ground. It is a circular cast-iron tank, containing about 800,000 gallons, divided into two concentric compartments; the inner one is 75 feet in diameter, and the outer, which is annular, has an outside diameter of 105 feet; there is an opening in the center for the staircase. The depth of the tank is 15 feet; it is covered with a wrought-iron trussed roof, which rests on the tank itself, and is boarded over and covered with zinc.

The tank is supported on a series of concentric and radiating brick walls. The author is informed by the engineer, Director Hegener, that when he took charge of the works there were leaks in the bottom of the tank, and that, in consequence of the above walls being built without openings, holes had to be cut through them to ascertain where the defects were. Eventually the whole of the bottom was covered with Portland cement concrete of sufficient depth to cover the flanges, which has been effectual in preventing further leakage. Only a fraction of the water consumed passes into this tank, which holds about one-seventh of the daily supply.

Cologne derives its water supply from two brick wells sunk within 28 yards of the river Rhine; they are 18 feet in diameter, and have a depth of 60 feet, or 36 feet below the lowest water level of the Rhine. The strata consists of sand and gravel mixed with boulders. At the depth of 46 feet, under a layer of large boulders, a bed of gravel 6 feet thick was met with, which was extremely hard, and took the divers many months to sink through; under this came clean, coarse gravel, from which the water is pumped. The daily yield is 5,000,000 gallons, with a depression of 21 feet in the wells. Although the wells are so close to the Rhine, the spring water obtained from the gravel is supposed to be without any admixture from the river, as the temperature of the spring water varies only 5° Fahrenheit compared with a variation of 38 degrees in the Rhine water, viz., from 32° to 70°. The spring water is also

much harder, being from 17° to 18°, whereas the Rhine water is only 7°.

The author has ascertained the particulars of the Dresden reservoir from "Das Wasserwork der Stadt Dresden," published by the engineer, Mr. B. Salbach.

It is built in the form of a parallelogram, divided by a wall into two compartments, each 172 feet long by 122 feet wide; the depth of water is 16 feet 6 inches, and the reservoir contains 4,400,000 gallons. The side walls, piers, cross arches and division walls are built in coarse masonry of sandstone, with cement mortar; the vaulting is formed of two rings of hard burnt porous bricks in cement, which is rendered externally to prevent the percolation of rain water into the reservoir. The side walls are 6 feet 9 inches, and the division wall 7 feet 6 inches thick; the piers are 40 inches wide by 20 inches thick; the span of the cross arches is 16 feet; the vaulting, which springs from top water-level, has a span of 16 feet, and a rise of 47 inches.

The excavation is in compact fine sand, over the bottom of which, including the foundations of the walls and piers, &c., a uniform thickness of 2 feet of concrete was laid. This consisted, in the first place of a layer of rough pieces of granite, with the flat side on the sand; above this a thin bed of concrete was spread and lightly rammed to fill the interstices betweeen the stones, and over this the concrete was deposited in the usual manner in 6-inch layers, and solidly rammed.

The concrete under the foundations of the walls and piers was laid first, and the rest, which forms the bottom of the reservoir, subsequently, and the surface was protected during the progress of the work by a course of brick-on-edge in cement; on the completion of the work two courses of bricks were laid flat, and the suface rendered in cement. The whole of the internal surfaces of the reservoir, including the piers, are rendered over with cement, with a hard, polished surface, partly for the purpose of making them watertight, partly to prevent the deposit of mud or slime in the interstices of the porous sandstone.

The Hanover reservoir, is situate on the Lindener Berg. In order to maintain a pressure in the city due to a height of 33 meters (108 feet) it was built entirely above ground, only sufficient soil being excavated to obtain a good foundation on the solid limestone.

The reservoir is completely exposed, without any embankment to support it, principally on account of the great expense which would have been involved in carting earth from a distance none being available near the site. Moreover, an embankment has its disadvantages, as it may possible cover up defects or leakages in the brickwork, which may do considerable damage before discovery; whereas, in a reservoir with the walls exposed the slightest leakage is at once detected. The reservoir consists of two divisions, each 106 feet long by 98 feet wide; the depth of water is 19 feet 6 inches, and it contains altogether about 2,400,000 gallons. It is built of hard burnt bricks in Portland cement mortar. The side walls have a trapezoidal profile, and are strengthened by buttresses: the inner side is vertical; the thickness at the base is 14 feet 9½ inches, and at the level of the springing of the vaulting, which corresponds with the top water-line, it is 7 feet 6 inches thick. The division wall, which has vertical faces and is stiffened by piers, is 9 feet 6 inches thick. The interior surface of these walls is rendered with Portland cement.

The bottom of the reservoir is formed of a layer of concrete from 3 feet 3 inches to 4 feet 6 inches thick, on which piers are built for supporting the arched cross wall to carry the vaulting. The piers are 4 feet 6 inches by 2 feet 6 inches, 15 feet high, and stand about 16 feet apart from center to center, transversely dividing the breadth of the reservoir into six equal parts, and about 15 feet from center to center longitudinally, so that each division of the reservoir is covered by seven vaults, which have a span of 12 feet, and a rise of 3 feet 3 inches. The upper surface of the vaulting is covered with sloping brickwork in cement, and rendered, above which there is a layer of 3 feet 3 inches of sand, over which succeed 6 inches of mould turfed over. The rain water percolating through this covering is conveyed into the reservoir through drain-pipes. The total height of the reservoir above the ground-level is 30 feet.

That part of the brickwork above the vaulting which merely serves to support the covering earth, is built with Roman

cement. The reservoir is fitted with fourteen ventilators. The floor is finished with four layers of Hanoverian clinker bricks laid in Portland cement mortar, and rendered in Portland cement hardened under the trowel, *i.e.*, the cement is worked under the trowel and pressed until it becomes hard and smooth.

The description and drawings of this reservoir are taken from "Das Neue Wasserwork der Koniglichen Residenzstadt Hanover," by Oberbaurath Berg.

The author was struck by the marked preference of the Germans for spring water as compared with lake or river water. In England it is generally assumed that the water from mountain lakes, such as Loch Katrine or Thirlmere, is the purest and most wholesome. The Germans object to such waters as being stagnant and dead; they prefer water as it gushes fresh and sparkling from the mountain side, and which has a constant temperature; whereas lake water is too cold in winter and warm and vapid in summer. Where natural springs are not available they prefer to tap the subterranean streams of water which, in many parts of Germany, flow either parallel with the rivers or down towards them from the surrounding country, rather than to use the water from the rivers, however well filtered or soft it may be. In fact, an equable temperature is deemed of the first importance in choosing potable water, a moderate degree of hardness not being objected to.

The following towns, the whole of which have populations exceeding 50,000, are supplied with water pumped from underground springs: Aix-la-Chapelle, Augsburg, Berlin, Cologne, Crefeld, Dantzig, Dresden, Dusselldorf, Elberfeld, Essen, Gratz, Halle, Hanover, Cassell, Königsberg, Leipzig. Nürnberg, Strasburg.

As compared with similar towns supplied from rivers: Altona, Berlin, Brunswick, Bremen, Breslau, Brunn, Hamburg, Magdeburg, Posen, Stettin.

These two lists comprise all the large towns of Germany and Austria, except such as are supplied from natural springs, as in Vienna and Frankfort, and those which have no properly organized system of water supply.

Design for Covered Service-Reservoir.

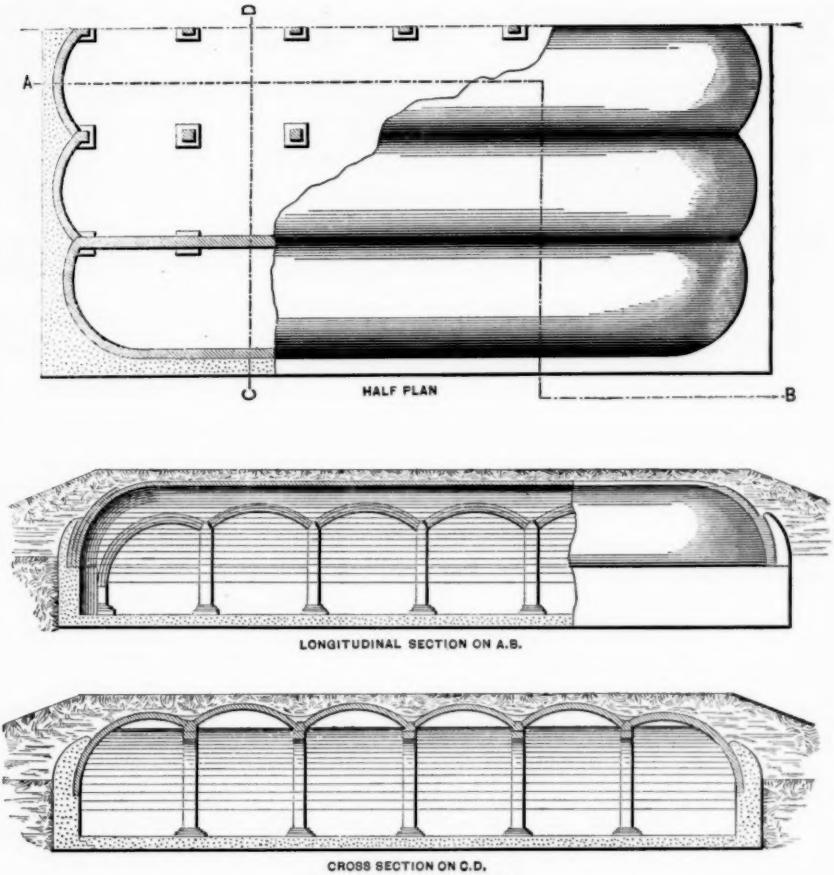
Having laid the foregoing examples of covered reservoirs before the Institution, the author proposes to conclude the paper with a sketch of his idea of a model Covered Service-Reservoir.

It should, if possible, be built on a level piece of ground, and the soil should be perfectly solid and homogeneous. These conditions are assumed to exist. The reservoir as designed is 100 feet square on plan, with a maximum depth of 17 feet, and would contain 1,000,000 gallons of water.

The design is so arranged that the earth dug from the excavation is utilized in covering the reservoir and forming the necessary embankments; the depth of the excavation will therefore depend on the slope given to the embankment. In this case, a slope of $2\frac{1}{2}$ to 1 is adopted; and it is calculated that an excavation 11 feet deep will furnish sufficient earth to form an embankment 13 feet above the ground-line, including a layer of soil 2 feet thick over the roof of the reservoir.

The author has adopted a similar construction to that of the Munich reservoir for the lower part of the structure, it being assumed that there will be no difficulty in obtaining good ballast for concrete in the neighborhood of the site.

The work should be commenced by digging trenches 7 feet wide and 11 feet deep for the reception of the outside walls (it will be convenient to designate the outer walls, which are parallel with the vaulting, the side walls, and those at right angles to the vaulting, the end walls). The bottom of these trenches should be covered with 18 inches of concrete, on which concrete side walls, 4 feet thick, and 7 feet 6 inches high, should be constructed, the concrete being rammed between the moulds for forming the internal face and the external earth. The end walls should be similar, except as regards the internal face which should have six curved bays, the radius of the curve being 11 feet 6 inches. As soon as the concrete in these walls has set, the moulds should be taken down, and the surface rendered with Portland cement worked with the trowel, till it becomes hard and smooth, and then finished with a film of neat cement worked to a fine polish.



DESIGN FOR RESERVOIR

If the ground be firm, the toe of the wall, supported by the internal earth, will be sufficient to sustain the wall against external pressure without strutting; but care should be taken not to load the ground outside the reservoir by the premature construction of the embankment. The internal earth or dumpling should now be removed down to the level of the toe of the wall, but in removing the earth below this level, which should be done piece-meal, the layer of concrete forming the floor of the reservoir should be at once substituted, the thickness of which, 2 feet, would when set be ample to resist any ordinary external pressure tending to thrust forward the toe of the wall.

The floor having been laid, the brick piers for supporting the vaulted roof should be built on it. These are 1 foot $10\frac{1}{2}$ inches square on plan, and 16 feet 8 inches from center to center in each direction. From these piers, at 13 feet from the floor, spring the arches which support the vaulting; the arches in the center have a radius of 11 feet 6 inches, but the two end arches, which have a radius of 9 feet 6 inches, are brought down, so that the thrust of each row of arches is carried below the ground-line.

The vaulting, which, is built with a

radius of 11 feet 6 inches, is similar to that of the Farnborough reservoir, but the ends of the covering arches are brought down with a curve of 12 feet 6 inches radius, till they rest on the correspondingly curved bays of the concrete end walls already described. The two exterior arches, being brought down at each end in a similar manner, form the rounded corners of the reservoir.

On the completion of the brickwork, the 2-feet space between the top of the concrete wall and the surface of the soil should be filled with concrete backing, which should be carried up to the height of 6 feet above the ground line. The earthwork of the embankment should now be proceeded with, and the floor and internal faces of the side arches rendered with Portland cement, to make the structure water-tight.

By the above arrangement, the thrust of the roof is carried down to an abutment, resting against undisturbed ground. The pressure of the water is not only supported by the same abutment, but it is also counterbalanced by the pressure of the made earth forming the embankment which rests on the exterior arches of the reservoir, in addition to the pressure of the earth, which would have to resist the internal pressure if the walls were vertical.

The author believes the above system of construction to be secure and economical, and that, by its adoption, the water-line may be raised higher above the original surface than could safely be done with vertical walls, unless such walls be made sufficiently thick to resist the pressure of the water without the aid of earthwork, as in the Hanover reservoir, which would add considerably to the cost.

Where favorable conditions of site do not exist, some modification of the above model would be necessary; such, for instance, as the use of puddle, should any settlement of the foundations be apprehended which might cause cracks in the structure.

THE GENERAL THEORY OF THERMODYNAMICS.

By Prof. Osborne Reynolds, M.A., F.R.S.

From "The Engineer."

Thermodynamics is a very difficult subject. The reasoning involved is such as could only be expressed in mathematical language; but this alone would not prevent the leading facts and features of the subject being expressed in popular language. The physical theories of astronomy, light and sound involve even more mathematical complexities than thermodynamics; but these subjects had been rendered popular, and this to the great improvement of the theories. What rendered the subject of thermodynamics so obscure was, that it dealt with a thing or entity (heat), which, although its effects could be recognized and measured, was yet of such a nature that its mode of operation could not be perceived by any of our senses. Had clocks been a work of nature, and had the mechanism been so small that it was absolutely imperceptible, Galileo, instead of having to invent a machine to perform a definite function, would have had, from the observed motion of the hands, to have discovered the mechanical principles and actions involved. Such an effort would have been strictly parallel to that required for the discovery of the mechanical principles of which the phenomena of heat were the result. In the imagined case of the clock, the discovery might have been made in two ways. By the scientific method; from the observed motion of the hands the fact that the clock depended on a uniform intermittent motion would have led to the discovery of the principle of the uniformity of the period of vibrating bodies; and on this principle the whole theory of dynamics might have been founded. Such a theory of mechanics would have been as obscure, but not more obscure than the theory of thermodynamics based on its two laws. But there was another method, and it was by this that the

theory of dynamics was brought to light —to invent an artificial clock, the action of which could be seen. It was from the actual pendulum that the principles of the constancy of the periods of oscillating and revolving bodies were discovered, whence followed the dynamical theories of astronomy, of light, and of sound.

As regarded the action of heat, no visible mechanical contrivance was discovered which would afford an example of the mechanical principle and motions involved, so that the only apparent method was to discover by experiment the laws of the action of heat, and to accept these as axiomatic laws without forming any mental image of their dynamical origin. This was what the present theory of thermodynamics purported to be. In this form the theory was purely mathematical, and not fit for the subject of a lecture. But as no one who had studied the subject doubted for one moment the mechanical origin of these laws, Professor Reynolds would be following the spirit if not the letter of his subject if he introduced a conception of the mechanical actions from which these laws sprang. This he should do, although he doubted if he should have so ventured, had it not been that while considering this lecture he hit upon certain mechanical contrivances, which he would call kinetic-engines, which afforded visible examples of the mechanical action of heat, in the same sense that the pendulum was a visible example of the same principles as those involved in the phenomena of light and sound. Such machines, thanks to the ready help of Mr. Foster, his assistant in constructing the apparatus, he should show, and he could not but hope that these kinetic engines might remove the source of the obscurity of thermodynamics on which he had dwelt. The general action of heat to cause matter to expand was sufficiently obvious and popularly known; also that the expanding matter could do work was sufficiently obvious. But the part which the heat played in doing this work was very obscure. It was known that heat played two, or it might be said three, distinct mechanical parts in doing this work. These parts were: (1) To supply the energy necessary to the performance of work. (2) To give to the matter the elasticity which enabled it to expand—to convert the inert matter into an acting machine. (3) To convey itself, *i. e.*, heat, in and out of the matter. This third function was generally taken for granted in the theory of thermodynamics, although it had an important place in all applications of this theory. The idea of making a kinetic engine which should be an example of action such as heat had no sooner occurred to him than various very simple means presented themselves. Heat was transformed by the expansion of the matter caused by heat. At first he tried to invent some mechanical arrangement which would expand when promiscuous agitation was imparted to its parts, but contraction seemed easier —this was as good. All that was wanted was a mechanism which would change its shape, doing work when its parts were thrown into a state of agitation. In order to raise a bucket from a well either the rope was pulled or the windlass wound—such a machine did not act by promiscuous agitation; but if the rope was a heavy one—a chain was better—and it was made fast at the top of the well so that it just suspended the bucket, then if it was shaken from the top waves or wriggles would run down the rope until the whole chain had assumed a continually changing sinuous form. And since the rope could not stretch, it could not reach so far down the well with its sinuosities as when straight, so that the bucket would be somewhat raised and work done by promiscuous agitation. The chain would have changed its mechanical character, and from being a rigid tie in a vertical direction would possess kinetic elasticity, *i. e.*, elasticity in virtue of the motion of its parts, causing it to contract its vertical length against the weight of the bucket. Now, it was easy to see in this case that to perform this operation the work spent in shaking the rope performed the two parts of imparting energy of motion to the chain and raising the bucket. A certain amount of agitation in the chain would be necessary to cause it to raise a bucket of a certain weight through a certain distance, and the relation which the energy of agitation bore to the work done in raising the bucket followed a law which, if expressed, would coincide exactly with the second law of thermody-

namics. The energy of agitation imparted to the chain was virtually as much spent as the actual work in raising the bucket, that was to say, neither of these energies could be used over again. If it was wanted to do further work, the raised bucket was taken off, and then to get the chain down again it must be allowed to cool, *i. e.*, the agitation must be allowed to die out; then attaching another bucket, it would be necessary to supply the same energy over again. He had other methods besides the simple chain, which served better to illustrate the lecture, but the principle was the same. In one there was a complete engine with a working pump. By mere agitation the bucket of the pump rose, lifting 5 lb. of water 1 foot high; before it would make another stroke the agitated medium must be cooled, *i. e.*, the energy which caused the elasticity must be taken out, then the bucket descended, and, being agitated again, made another stroke. He felt that there was a childish simplicity about these kinetic engines, which might at first raise the feeling of "Abana and Pharpar" in the minds of some of his hearers. But this would be only till they realized that it was not now attempted to make the best machine to raise the bucket, but a machine that would raise the bucket by shaking. These kinetic engines were no mere illustrations or analogy of the action of heat, but were instances of the action of the same principles. The sensible energy in the shaking rope only differed from the energy of heat in the scale from the energy of heat in a metal bar. The temperature of the bar, ascertained from absolute zero, measured the mean square of the velocity of its parts multiplied by some constant depending on the mass of these parts. So the mean square of the velocity of the links of the chain multiplied by the weight per foot of the chain, really represented the energy of visible agitation in the chain. The waves of the sea constituted a source of energy in the form of sensible agitation; but this energy could not be used to work continuously one of these kinetic machines, for exactly the same reason as the heat in the bodies at the mean temperature of the earth's surface could not be used to work heat engines. A chain attached to a ship's mast in a rough sea would become elastic with agitation, but this elasticity could not be used to raise cargo out of the hold, because it would be a constant quantity as long as the roughness of the sea lasted. Besides the waves of the sea, there was no other source of sensible agitation, so there had been no demand for kinetic engines. Had it been otherwise, they would not have been left for him to discover—or had they been, he might have been tempted to patent the inventions. But there had been a demand for what might be called sensible kinetic elasticity, to perform for sensible motion the part which heat elasticity performed in the thermometer. And it had not been left for him to invent kinetic mechanism for this purpose, although it might be that its semblance to the thermometer had not been recognized. The principle was long ago applied by Watt. The common form of governors of a steam engine acted by kinetic elasticity, which elasticity, depending on the speed at which the governors were driven, caused them to contract as the speed increased. The governor measured by contraction the velocity of the engine, while the thermometer measured by expansion the velocity in the particles of matter which surrounded it; so that it could now be seen that having to perform two operations, the one on a visible scale, the other on a molecular scale, the same class of mechanism had been unconsciously adopted in performing both operations. The purpose for which these kinetic engines was put forward was not that they might be expected to simplify the theory of thermodynamics, but that they might show what was being done. The theory of thermodynamics could be deduced from the laws of motion from any one of these kinetic engines, just as Rankine deduced it from the hypothesis of molecular vortices. Nothing had yet been said of the third part which heat played in performing work, namely, in conveying heat in and out of matter. It was an innovation to introduce such considerations into the subject of thermodynamics, but it properly had a place in the theory of heat engines. It was on this part that the speed at which an engine would perform work, depended. The kinetic machines showed this. If one end of a chain was shaken the wriggle ran along with a definite speed,

so that a definite interval must elapse before sufficient agitation was established to raise the bucket; further, an interval must elapse before the agitation could be withdrawn, so that the bucket might be lowered for another stroke. The kinetic machine, with the pump, could only work at a given rate. He could increase this rate by shaking harder, but then he expended more energy in proportion to the work done. This exactly corresponded with what went on in the steam engine, only owing to the use of separate vessels, the boiler, cylinder, and condensers, the connection was much confused. But it was clear that for every horse-power (2,000,000 foot-pounds per hour), 15,000,000 foot-pounds had to be passed from the furnace into the boiler, as out of the 15,000,000 no more than 2,000,000 could be used for work, the remaining 13,000,000 were available for forcing the heat into the boiler and out of the steam in the condenser, and they were usefully employed for this purpose. The boilers were made as small as sufficed to produce steam, and this size was determined by the internal temperatures of the gases in the furnaces, and the water in the boiler; and whatever diminished this difference would necessarily increase the size of the heating surface required, *i. e.*, the weight of the engine. The power which this difference of temperature represented could not be used in the steam engine, so it was usefully employed in diminishing the size of the engine. Most of this power, which in the steam engine was at least eight times the power used, was spent in getting the heat from the gases into the metal plates, for gas acted the part of conveyance far less readily than boiling water or condensing steam. If air had to be heated inside the boiler and cooled in the condenser with the same difference of temperature, there would be required thirty or forty times the heating surface—a conclusion which sufficiently explained why attempts to substitute hot air for steam had failed. In one respect the hot air engines had an advantage over the steam engine. During the operation in the cylinder the heat was wanted to be kept in the acting substance; this was easy with the air, for it was such a bad conductor of heat that unless it was in a violent state of internal agitation it would lose heat but slowly, although at a temperature of 1000 deg. and the cylinder cold. Steam, on the other hand, condensed so readily that the temperature of the cylinder must be kept above that of the steam. It was this fact which limited the temperature at which steam could be used. Thus, while hot air failed on account of true economy, the practical limit of the economy of steam was fixed by that which a cylinder could bear. These facts were mentioned because at the present time there appeared to be the dawn of substituting combustion engines in place of steam engines. Combustion engines, in the shape of guns, were the oldest form of heat engine. In these, the time required for heating the expansive agent was zero, while they had the advantage of incondensible gas in the cylinder, so that if the cylinder was kept cool it cooled the gas but slightly, although this was some 3000 deg. in temperature. The disadvantage of these engines was that the hot gas was not sufficiently cooled by expansion, but a considerable amount of the heat carried away might be used again could it be extracted and put into the fresh charge; to do this, however, would introduce the difficulty of heating surface in an aggravated form. However, supposing the cannon to have been tamed and coal and oxygen from the air to be used instead of gunpowder. Thermodynamics showed that such engines should still have a wide margin of economy over steam engines, besides the advantage of working with a cold cylinder and at an unlimited speed. The present achievement of the gas engine, stated to be some 2,000,000 foot-pounds per ton of coke, looked very promising, and it was thus not unimportant to notice that whatever the art difficulties might be, thermodynamics showed no barrier to further economy in this direction, such as that which appeared not far ahead of what was already accomplished with steam engines. But however this might be, he protested against the view, which seemed somewhat largely held, that the steam engine was only a semi-barbarous machine, which wasted ten times as much heat as it used—very well for those who knew no science, but only waiting until those better educated had time to turn their attention to practical matters, and then to give place

to something better. Thermodynamics showed the perfections, not the faults of the steam engine, in which all the heat was used, and could only enhance the admiration in which the work of those must be held who gave us, not only the steam engine, but the embodiment of the science of heat.

ON THE COMPARATIVE ENDURANCE OF IRON AND MILD STEEL WHEN EXPOSED TO CORROSIVE INFLUENCES.

By DAVID PHILLIPS, M. Inst. C. E.

From Proceedings of the Institution of Civil Engineers.

I.

Iron and so-called mild steel have been subjected from time to time to such elaborate mechanical tests, at the hands of so many practical men, as to render further investigation into their comparative strength and ductility almost unnecessary; but the endurance of these metals when exposed to corrosive influences, a subject scarcely second in importance to that of their strength, has been almost entirely neglected. Excepting the work of the late and the present Boiler Committees of the Admiralty, and of some government officers, there are, the author believes, the results of only a very few experiments on record.

Having regard to the numerous discussions which have taken place during the last three years respecting the materials best suited for the construction of ships, boilers, and bridges, and remembering the efforts that have been made to perfect mild steel for those purposes, it is extraordinary that the subject should have received so little attention. Even the opinions advanced by experts are conspicuous by their lack of reliable information, opinions emanating nevertheless from those who would doubtless be able to give valuable information were the question fairly treated. But recent discussions, the author thinks, have afforded evidence of partiality, mild steel finding advocates in abundance, while the question of its endurance when exposed to corrosive influences, as compared with iron, appears, from the consumer's point of view, to have been purposely neglected.

The author had the honor to serve on the committee appointed by the Admiralty in June, 1874, to inquire into the causes of corrosion in boilers, and since its dissolution he has made further experiments with the same objects in view. He trusts that his efforts to throw light on the matter may be of advantage to the profession. It will be necessary for the purpose he has in view to refer to several of the experiments made by the late Boiler Committee, as well as to his own; and it may be remarked in passing that it would have been satisfactory to all interested in engineering matters, had the results of the last twelve months of the labors of the committee, and of the experiments continued at Devonport after its dissolution, been published before this.

In this paper it is proposed to treat chiefly of the comparative durability of iron and mild steel when exposed to similar influences. The action on these metals of various kinds of water in the presence or absence of air, alkalies, &c., is too wide a subject to include, even if it had not already been treated by the Chairman of the late Boiler Committee, Rear-Admiral C. Murray Aynsley, C. B.

The first experiment to be mentioned is that referred to in the third report of the late committee, p. xi. Six sets of tubes of different brands of iron and steel, prepared for the purpose, were tested in a special apparatus in Sheerness dockyard, with the view of ascertaining their comparative durability. The sets were numbered from 1 to 6, but as some of the tubes became unfit for testing, sets 1 and 6 will be only incidentally referred to. The remaining four sets con-

sisted severally of tubes of one of each of the following brands, viz.:

A.I. Lloyd and Lloyd's improved metal (iron.)
B.W. Whitworth's compressed steel.
B.F. Fagersta Bessemer steel.
C. Bolton Iron and Steel Co.'s Bessemer steel.
D. Crampton's thrice-hammered iron.
E. Lloyd and Lloyd's improved homogeneous metal (iron.)
F.F. Firth and Sons' crucible steel.
F.S. Ordinary iron (not specially prepared.)
G. Cammell and Co.'s special steel.

Sets 2 and 3 had each in addition a Yorkshire iron tube (A.Y. 15 and 19) thus making the total number of tubes thirty-eight, eighteen being of iron and twenty of steel. The Whitworth, Fagersta, and Firth's steel, and the Crampton iron tubes, were cold-drawn, the others were welded. The cold-drawn tubes had originally a smooth and clean surface, with only a film of oxide, the result of annealing, whilst the welded tubes, especially those of iron, were rather rough, with the usual coating of oxide. This would be in favor of the steels in calculating the losses of weight. All the tubes were carefully weighed before and after each experiment, and were 8 feet in length and 2½ inches in diameter, representing an exposed surface inside and out of 9.58 square feet, with the exception of the ordinary iron tubes (Fs), which were 2 inches in diameter, and had 7.68 square feet of exposed surface.

The testing apparatus consisted of two cylinders, 3 feet 7 inches in diameter, and 6 feet in height, the tubes being screwed tightly through the top ends.

TABLE I.

	Kind of Water, Alkali, &c., in Tubes,				Loss of Weight.			
	Set 2. Density and 500 grs. of Lime; air admitted weekly.	Set 3. Sheerness Well, no Alkali; Air admitted weekly.	Set 4. Rain, and 500 grs. of Soda; Air excluded.	Set 5. Distilled from Sea Water, no Alkali, Air excluded.				
Tubes.	Loss of Weight.	Loss of Weight.	Loss of Weight.	Loss of Weight.	Total Loss of Weight.	Mean Loss per Tube.	Average Loss per Sq. Ft. of Surface.	Average Loss per Square Foot of Surface.
	Oz.	Oz.	Oz.	Oz.	Oz.	Oz.	Oz.	Grs.
Steel B.W...	21.25	28.00	20.25	11.25	80.75	20.19	2.1072	921.90
" B.F..	24.00	27.25	15.75	12.50	79.50	19.87	2.0746	907.63
" C.....	23.75	23.00	22.00	13.25	82.00	20.50	2.1398	936.16
" F.F...	21.25	16.50	17.00	18.25	73.00	18.25	1.9050	833.43
" G.....	20.25	16.25	18.75	16.50	71.75	17.94	1.8723	819.13
Total loss...	110.50	111.00	93.75	71.75	387.00	..	..	169,312.50
Mean loss...	22.10	22.20	18.75	14.33	19.35	..	2.0197	883.66
Iron A.I....	12.75	11.75	14.50	13.25	52.25	13.06	1.3635	596.53
" D.....	15.50	16.00	17.25	12.25	61.00	15.25	1.5918	696.41
" E.	14.00	17.25	25.25	12.00	68.50	17.12	1.7876	782.07
" F.S....	6.00	7.00	5.00	3.75	22.25	5.56	0.7113	311.19
" A.Y....	14.25	11.50	..	..	25.75	12.87	1.3440	588.00
Total loss...	62.50	63.50	62 50	41.25	229.75	..	..	100,515.62
Mean loss...	12.50	12.70	15.62	10.31	12.77	..	1.3890	607.71

The lower parts of the tubes, 5 feet 8 inches in length, thus confined in the cylinders and filled with various kinds of water, were exposed during the working hours in the yard to an average steam pressure of 50 lbs. per square inch, the steam being supplied from one of the factory boilers close by; whilst the upper parts, representing, as it were, the steam spaces of boilers, were inclosed in a chamber open to the air, and supplied with sufficient cold water to insure partial condensation of the steam within. The average steam pressure in the tubes was thus kept at about 38 lbs. per square inch.

In table I were the conditions of working, and the losses of weight of the tubes after a little more than two years' trial.

Taking all the four sets, representing 191.6 square feet of steel, and 165.4 square feet of iron, the results are as follows:

TABLE II.

No. of tubes.	Metal.	Total loss of weight.	Average loss per sq. ft. of surface.	Percentage in favor of irons.
		Oz.	Grs.	
20	Steels	387.00	883.66	45.4
18	Irons	229.75	607.71	

Taking sets 2 and 3 only, representing 95.8 square feet of steel, and 92.28 square feet of iron, the following is the result:

TABLE III.

No. of tubes.	Metal.	Total loss of weight.	Average loss per sq. ft. of surface.	Percentage in favor of irons.
		Oz.	Grs.	
10	Steels	221.5	1,010.50	69.2
10	Irons	126.0	597.36	

The tubes in each set were under precisely similar treatment; consequently the loss of weight of each of the different brands is a fair criterion of their comparative durability.

Illustrations are exhibited of gutta-percha impressions taken from parts of some of the tubes at different levels. They give a fair idea of the nature, as well as of the severity, of the corrosion. The specimens are arranged in order, according to the severity of the corrosion, as deduced from the examination of their interior surfaces, but in weight the ordinary iron lost the least, and the Fagersta and the Whitworth steels the most; and they represent respectively set 2; the exterior suface at about the water-level in the condensing chamber, the interior surface in the steam space, at the water-level, and the bottom ends of the tubes.

The Barrow steel tubes, H 2 and 3, were tested only half as long as the others; taking this into account, it will be seen by the impressions that the corrosion was exceptionally severe. The group marked A and G represents set 4: and that marked Fs and Bw, set 5. The A and Fs were the least, and the G and Bw the most affected of the two last sets, which compare favorably with sets 2 and 3. The impressions in the center of the top row were taken from the interior surfaces of AY and I tubes at the water-line and at the bottom ends. Only two of these tubes, 15 and 19, were under similar conditions to sets 2 and 3, and are included in the four sets before mentioned.

Small disks of iron and steel of various brands were also tested in another group of tubes in the apparatus. Impressions taken from these, and from some pieces of the same metals, which were tried in boilers at Devonport, are likewise illustrated. Full particulars of these experiments will be found in the third report of the committee, appendices G and H, pp. 267-268, and 281-284.

All the specimens, tried in boilers, from which the impressions were taken, had originally bright surfaces. The top row represents the disks in contact with zinc; the second row those with no zinc present.

There was a striking difference between the iron and steel disks, and also between the several steels as regards the nature and severity of the corrosion. While the disk O (steel) was very uni-

formly affected, the disk V was deeply pitted; yet the loss of weight in the latter was 19 grains less than in the former. The O 2 from the same plate as the O disk was much rougher, while the loss of weight was 18.8 grains less. The A disk (steel) was peculiarly affected, being pitted in small deep holes, whilst the intervening surface was scarcely touched. Again, the edges of some of the disks were corroded uniformly, whilst others were affected in a most extraordinary manner, especially the R, A, and Y steel disks. The edges of the Y iron disks were corroded in ridges and grooves, showing plainly that the bloom had been made up by ordinary piling, and that the piles could not have been of uniform quality.

The metals in this experiment were doubtless exposed to a severe test. They were suspended in copper tubes, filled with water of $\frac{8}{32}$ density, with tallow as a lubricant, air being admitted weekly. The duration of the experiment was six months only.

Impressions taken from pieces of iron and steel of various brands, which were suspended for twelve months in one of the boilers of the Trusty, a tug having a jet condenser, and worked at a low pressure, are also shown. The bottom row represents the set that was in the water, and the other the duplicate set that was in the steam space. These pieces were cut from plates which were subjected to cold bending and other tests, as described in the Reports of the Boiler Committee. Excepting the edges, the surfaces were rough. The Whitworth compressed and the Siemens' steels were not included in this group, on account of the delay in their production. In this experiment again, the loss of weight in the steels, and the nature of the oxidation were remarkable. The percentage in favor of the irons was 32.7; in the disk experiment it was 56.7.

The same set of plates, with others of Whitworth's, Simens', and Attwood's steels added, were tried for another twelve months in a feed-water heater supplied with fresh water, and a duplicate set in one of the boilers of the Perseverance, a tug worked at a low pressure and fitted with surface condensers. The surfaces of the specimens had all been made bright. The percentage in favor of the irons was 27.5 in the tug, and 11.8 in the feed-water heater. The pieces of metal tested in these experiments were very small, but the results are not without significance.

Plates of Bolton steel and Lowmoor iron, 10 inches long by 8 inches wide, by $\frac{9}{16}$ and $\frac{7}{16}$ inch thick respectively, were also placed in the boilers of the two tugs before mentioned. They were suspended with the view of ascertaining the comparative effects of fastening together plates of steel and iron with brass and with iron stay; and also the action of zinc on two plates, steel and iron, connected together, when attached to only one of them. Eight plates of each metal, representing 9.9 square feet of steel, and 9.68 square feet of iron, were tested. The result from one-half of the specimens after thirteen months' trial was as follows:

TABLE IV.

No. of plates.	Metal.	Total loss of weight.	Average loss per sq. ft. of surface.	Percentage in favor of irons.
		Oz. Grs.	Grs.	
4	Steels	7 209.3	659.63	32.7
4	Irons	5 218.7	497.14	

The corrosion in the steel plates, in the form of "pitting," was so marked, and the difference between the plates from the Trusty and from the Perseverance so great, that all these eight plates were forwarded to the Admiralty for inspection. The result of the trial of the other eight, four for twenty-one and four for twenty-two months, was as follows:

TABLE V.

No. of plates.	Metal.	Total loss of weight.	Average loss per sq. ft. of surface.	Percentage in favor of irons.
		Oz. Grs.	Grs.	
4	Steels	10 382.9	959.25	28.6
4	Irons	8 109.4	745.74	

The impressions taken from one-half of these plates, though slightly distorted, give a fair idea of the corrosion sustained by the two metals. N 5 was taken from one of the steel, and D D 6 from one of the iron plates.

Plates of the same metals, 15 inches long by 8 inches wide by $\frac{1}{2}$ inch and $\frac{3}{8}$ inch thick respectively, was also tested in the feed-water heater before mentioned.

The result after thirteen months was:

TABLE VI.

No. of plates.	Metal.	Total loss of weight.	Average loss per sq. ft. of surface.	Percentage in favor of irons.
		Oz. Grs.	Grs.	
2	Steels	19 327.9	2,453.9	10.9
2	Irons	17 218.7	2,212.2	

The impressions were only taken from a part of each of the plates in consequence of their size; but they show fairly well the nature of the extraordinary corrosion which occurred. The corrosion in the steel plates was only a little more marked and irregular than in the iron. Impressions 5 and 6 were taken from the tieplate, and 7 and 8 from the shell of a small steel boiler doing harbor duty at Chatham, which show very deep pitting. One group of impressions represents plates of Lowmoor iron and of Landore steel, 4 inches square by $\frac{3}{8}$ inch thick, which were suspended in pairs in vessels under slightly different conditions for a period of six months. Those marked 3 were in the same feed-water heater as the last-named plates. The result was:

TABLE VII.

No. of plates.	Metal.	Total loss of weight.	Average loss per sq. ft. of surface.	Percentage in favor of irons.
		Oz. Grs.	Grs.	
4	Steels	1 85.0	506.24	4.8 nearly
4	Irons	1 73.5	483 17	

The only peculiarity worth noticing in this experiment is that, while the two plates in the feed-water heater lost 381.8 and 394.2 grains, the two in the boiler fed from the heater lost only 8.0 and 3.4 grains respectively. In a former experiment, when iron only was placed in the feed-heater and boiler in question, the plate in the heater lost 405 grains, whilst that in the boiler lost during thirteen months only 20 grains. The heater was an open vessel, and the boiler was worked at a pressure of about 55 lbs. to the square inch.

The next experiments to be mentioned are a series made with iron and steel plates, 4 inches square by $\frac{3}{8}$ inch thick, suspended in the boilers of different ocean and coast-going steam vessels belonging to various ship owners.

The results are interesting from more points of view than one; but in this paper they will be treated chiefly as affecting the subject under consideration, the effects of the different treatments they experienced having been already dealt with by Admiral Aynsley. However different the treatments, and whatever the effects, it should be remembered that the five plates, all of different metals, of which each set consisted, were always under precisely similar conditions, whether in or out of the boiler. The exposed surface of each plate was 37.89 square inches, and the aggregate surface of each kind of metal in the fifty-six sets which have come under the author's notice was 14.74 square feet, or 44.22 square feet of steels, and 29.48 square feet of irons. The five metals were crucible, Bessemer, and Siemens steels, and B B Staffordshire and best Yorkshire irons. The periods of trial varied from five months to two and a half years.

The gross results are given in table VIII.

The impressions taken from a few of these sets are shown, and are interesting as illustrating the character of the corrosion caused by a change of conditions, such as the waters used, different practices of blowing off, &c., as well as the comparative effects on the different metals.

To venture a little beyond the subject of the paper, it may be observed that the difference in the condition of some

TABLE VIII.

Number of plates.	Metal.	Total loss of weight.	Average loss per square foot of surface.	Percentage in favor of the irons.
		Oz. Grs.	Grs.	
56	J. Crucible Steel.....	97 70.8	2,885.83	14.3 good.
56	N. Bessemer "	118 229.4	3,520.32	Or over.
56	Y. Siemens "	116 166.8	3,456.67	N and Y only (mild steels).
56	B.B. Staffordshire Iron..	92 163.0	2,743.58	21.3 good.
56	D.D. Yorkshire " ..	101 115.7	3,007.68	..

of the sets is remarkable. For example, in sets 2 and 43 the character of the corrosion was quite different; and whilst the mean loss of weight of set 43, after being in the boiler two hundred and eighty-five days, was 347.7 grains, that of 2, after being in the boiler three hundred and eleven days, was 825.4 grains, or per day as 1 to 2.1.

The boiler in which set 43 was suspended was filled fourteen times with fresh water, 2 inches of water being blown off daily, whilst that in which set 2 was hung was filled eight times with fresh and five times with sea water, 3 inches of water being blown off daily at sea, and 12 inches at intermediate ports.

A limited quantity of zinc was certainly present, though only suspended loosely, in the boiler with set 43, and to this its better condition may perhaps be attributed; but on comparing set 62 with 43, it would appear that the zinc had no influence on the plates.

Boiler 62 was employed in the same trade as boiler 2, namely, India and China. The plates were in the boiler two hundred and ninety-eight days, during which period it was filled five times with fresh water, 1 inch being blown off daily, and no zinc present, yet the mean loss of weight was only 364.9 grains as compared with 825.4 grains in set 2; or per day as 1 to 2.1.

Again, comparing set 84 with 62, the bad effects of much blowing off are manifested. Set 84 was only forty-three days in the boiler, which was filled during that period four times with sea and once with fresh water, whilst, extraordinary as it may seem, an average of 73 inches of water ws blown off daily. This, with the waste from other sources, was made up from the sea. The mean loss of weight in this set was 575.7 grains, as against 364.9 grains in set 62, being at the rate, per month of thirty days, of 401.7 grains in the former against 36.7 grains in the latter, or nearly twelve times as much.

As the boilers in these cases were fed from surface condensers and worked at a high pressure, it may be of interest to compare the results with those obtained from two jet-condensing low-pressure boilers, though this type is almost a thing of the past. Referring then to set 9, and set 63, the mean loss in each was practically the same, viz., 1,332 and 1,333.8 grains. Set 63 was one hundred and seventy-four days in the boiler; there is no record of the time that set 9 was in the boiler, but the total time was nearly the same as for the former set.

Comparing these results with those obtained from set 2, which was subject to the old, or perhaps the ordinary surface-condensing treatment, the loss from corrosion was nearly three times as much in the jet-condensing boilers, or per day as 2.8 to 1. Again, comparing these two sets, 9 and 63, with set 62, which was subjected to something like the most improved method of working, the loss in jet-condensing boilers was about six times that in the boiler with surface-condensers, namely a mean loss of 1,332.9 grains as compared with 364.9 grains, or per day as 6.2 to 1.

These results clearly prove that the conclusions arrived at by many experienced engineers and chemists as to the causes of corrosion in boilers, previous to the appointment of the Boiler Committee, were erroneous; but the conclusions are nevertheless still believed in to

TABLE

Number of Set.	Metal.	Water.	Loss of weight. First twelve months.	Second twelve months.	Total.	Average pr. sq. ft. of surf'ce	Percentage in favor of the—
			Grs.	Grs.	Grs.	Grs.	
98	N. Bessemer steel.....	Rain water.	186.7	141.4	328.1	1,246.9	Irons = 7.2, including J,† 9.4 nearly
	Y. Siemens steel.....		174.1	147.0	321.1	1,220 3	
	B.B. Staffordshire iron		165.3	119.0	284.3	1,080.5	
	D.D. Yorkshire iron. ...		185.1	136.2	321.3	1,221.1	
99	N. Bessemer steel.....	Sea water.	42.4	36.9	79.3	301.4	Iron = 5.7
	Y. Siemens steel.....		33.5	34.7	68.2	259.2	
	B.B. Staffordshire iron		35.4	35.6	71.0	269.8	
	D.D. Yorkshire iron.....		36.9	31.6	68.5	260.3	
100	N. Bessemer steel....	Exposed to weather and dipped in sea water daily.	1,044.7	501.6	1,545.6	5,874.0	Iron = 128.3
	B.B. Staffordshire iron		417.9	259.1	677.0	2,572.9	
	Y. Siemens steel.....	Exposed to weather only	234.4	135.9	370.3	1,407.3	Iron = 84.8
	D.D. Yorkshire iron		147.6	52.7	200.0	761.2	
101	N. Bessemer steel.....	Exposed to weather and dip'd in fresh water daily.	227.9	..	..	866.1	Iron=169.7
	B.B. Staffordshire iron		84.5	..	..	321.1	
	Y. Siemens steel.....	In kitchen tank along with J. 99.	134.5	..	..	511.2	Iron=7.4 good
	D.D. Yorkshire iron.....		125.2	..	.	475.8	
102	N. Bessemer steel.....	Rain water direct from the clouds filtered.	28.5	..	..	108.3	Steels=20 0
	Y. Siemens steel.....		28 8	..	..	109.5	
	B.B. Staffordshire iron		30.7	..	..	116.7	
	D.D. Yorkshire iron*....		38.1	..	..	144.8	
†98	J. Crucible steel†....	Rain in water butt.	198.4	146.2	344.6	1,309.6	99 over 98 =20.4
99	J. Crucible steel.....	Sea water in kitchen tank.	166.3	119.8	286.1	1,087.3	100 over 98 =52.1 good
100	J. Crucible steel.....	Sea water in kitchen boiler.	118.9	107.6	226.5	860.8	100 over 99 =26.3 good

* Cinder removed after the plate was weighed and included in the loss given.

some extent, and the mode of working consequent thereon followed.

The author will now describe the experiments he made with five sets of

IX.

Remarks on the appearance of the surfaces before testing.	Remarks on the appearance of the surfaces after testing.
Clean and bright all over.....	Slightly pitted in small spots, and corroded in large patches, the Y. being the least and more generally corroded of the two, but not very much discolored.
Very dirty on one face.....	Less affected and more generally of any of the set.
Slightly dirty on both faces (cinder).....	Much the same as Y., but more generally affected of the two, and only slightly discolored.
Clean and bright all over.....	Scarcely at all affected, except at top corners, which are black; the Y. is slightly touched under the hole on one face; both are nearly bright otherwise.
Very dirty on one face.....	Top corners of both black; one face of the B.B. slightly touched under the hole; crystalline appearance, but finer than D.D.; otherwise both appear dirty.
Slightly dirty on both faces (cinder).....	
Clean all over.....	Very rough and deeply marked all over.
Slightly dirty.....	Very much less marked; no comparison between the two.
Clean all over.....	Slightly marked all over, the Y. being more affected under the hole on both sides; generally the difference is not much.
Slightly dirty all over.....	
Clean all over.....	Marked all over; slight at top, increasing in severity downwards in both; but much more severe in N. than B.B.; the latter has a few very minute bright specks on one face after cleaning (something like minute blisters).
One face very dirty; the other better.....	Corroded in patches, which are very local in both; nearly half the surface scarcely at all affected. Slightly more locally affected and marked in the Y., but very similar to the J. 99.
Clean all over.....	
One face very dirty; the other one half only.....	
Perfect all over.....	Very slightly affected along the top edges, the corners are black, the rest being nearly bright.
Very dirty over; laminated in one corner. One face slightly dirty; the other very dirty. Cinder picked out and impression taken of it.....	These are a little more marked, due no doubt to cinder; surface generally crystalline, the B.B. having bright spots much more prominent than 99, projecting in the form of minute blisters above the surface.
Clean all over..	Corroded similarly to N. and Y. 98, but slightly more marked. Similarly affected to the last, but a little more local. Generally unaffected, but black, with small patches of pitting, and pin-holes here and there. Bottom edge on both sides severely affected for three-eight inch up, with a few deep pit-holes on edges.

† Comparable with the other 98 specimens.

plates, similar to those tested in ocean steamers. The conditions to which some of these plates were subjected, and the results obtained, are scarcely, if at all,

less important than those of the experiments last described. They are given in table 9 (see pages 134 and 135). To avoid even a suspicion that galvanic action had any influence in these cases, all the plates were suspended on glass rods, and each plate was separated from its neighbors by glass ferrules. Sets 98, 99, and 100 were under test for two years; sets 101 and 102 for only half that period. During the first twelve months set 98 lost considerably more than 99, and as this might have been due to the action of soot brought down from the roof, or of the lead of the water-butt, or both, set 102 was suspended in an earthenware pan similar to that containing 99, but filled with rain water direct from the clouds, and filtered.

Taking the aggregate losses of the irons and steel, omitting the crucible steels, the result was as follows:

TABLE X.

No. of plates.	Metal.	Total loss of weight.	Average loss per square foot of surface.	Percentage in favor of irons.
		Oz. Grs.	Grs.	
10	Steels	7 69.8	1190 41	64 8 nearly
10	Irons	4 150.6	722.42	

Impressions taken from these sets of plates, after twelve months' exposure, and at the end of two years, are shown. There is little to remark concerning the results, except that the corrosion is strikingly local and severe in set 98, which was placed in rain water; also that wetting the metals daily, especially with sea water, and exposing them to the weather, causes very severe corrosion, which the irons, as shown by the table, resisted much better than the steels.

The crucible steels illustrate further the action on metals of the same sort of water under slightly different conditions: The specimen J 98 was in a butt which received water direct from the roof, 89 was in a small tank in the kitchen, supplied by hand with water from the butt, and 100 in a small boiler supplied with water from the tank, for culinary purposes.

In years gone by the rapid and sometimes sudden deterioration of boilers was attributed to galvanic action, supposed to be set up between the copper or brass tubes of the condensers and the iron of the boilers. Although this theory may be regarded as obsolete, others equally speculative have taken its place. Galvanic action is now said to be set up between steel and steel, or iron and iron, if they differ in the slightest degree in composition; between metals and the cinders too frequently found unfortunately pressed into them by the rolls; but especially between iron and steel, and between the metals composing boilers and the oxides with which they are coated. The galvanometer is a very sensitive instrument, and would, no doubt, show whether one metal were negative to another, or whether such differences existed between metals and their oxides as would produce galvanic action; but practically these theories are in the author's opinion unworthy of much consideration. They are advanced by the ardent advocates of mild steel, and, as the author thinks, are only a cloak to cover the too indiscriminate advocacy of that material.

It is easy to say that the purer classes of metals ought to offer greater resistance to corrosion than the impure kinds. Accepting the theories advanced by the advocates of mild steel, this is undoubtedly a necessary conclusion; for all classes of iron, and especially the commoner brands, have invariably a thicker coating of oxide than the steels, and moreover have the great drawbacks, cinders and laminations, which it is professed are unknown in steel. But in spite of these reasonings, it is undoubtedly a fact, that under almost all circumstances iron, and particularly the harder classes, is far superior to the finer steels in its resistance to corrosion, and this the experiments described by the author incontestably prove.

As regards uniformity of composition, and temper also, steel has probably more than its fair share of praise. Laminations and cinders are undoubtedly the great objection to iron as now made, and this is well illustrated in the Cx group of impressions taken from one of the tubes tested. The center impression shows the inner layer of a blister corroded

through, and a large cavity thus formed in the tube; the one just above shows a blister punctured by a sharp-pointed instrument, while that below shows blisters untouched. It will be seen from these how easily original defects in the manufacture of tubes or plates, such as cinder, may be mistaken for what is called "pitting."

In these respects mild steel is no doubt much superior to iron, but that it is not without original defects, such as want of homogeneity and uniformity of temper, will be seen from another series of impressions. Here in some of the Y and J plates, there was to all appearance a small hard spot, which seems like a small pit surrounded by a slight ring. It should be borne in mind that these marks in the impressions appear the reverse of reality, the pits being spots much less acted upon, and the rings surrounding them grooves much more acted upon, than the rest of the surface of the plates.

Another plate (also Y), placed in the feed-water heater before referred to, had a spot, about $\frac{3}{8}$ inch in diameter, untouched by corrosion. After the plate had been six months under water the spot was quite bright, had its edge well defined, and was surrounded by a very slight groove; but the corrosion generally was trifling in this plate.

Some of the steel disks and tubes, especially the Whitworth's and Firth's, presented after testing a damaskeen appearance, being marked, very similarly to gun-barrels, with slightly and beautifully formed ridges and grooves.

Want of uniformity on the part of the steels will also be seen in Table 1 in the appendix, giving the results of the cold-bending test of the metals tested in the tube apparatus. Although three out of the five brands of steel had stood the severe test of being drawn cold from blooms, with only a small hole drilled through the center, there were surprising differences of temper, not only between the various brands, but also between the different tubes of each brand. Some of them, especially the Firth's, Barrow and Whitworth's, split up in various directions, and broke in several pieces whilst going through the ordeal of cutting open longitudinally, for the inspection of their interior surfaces, whilst others of the same brands showed scarcely any distress. It was on account of this that strips were cut from the tubes and subjected to the tempering test.

On comparing also the behavior of the tempered with that of the annealed specimens under the cold-bending test, the results are unsatisfactory. For whilst three of the metals after annealing were bent, doubled and then hammered flat, without exhibing any but the slightest signs of distress, after tempering the same metals only stood bending to the following angles before showing distress, viz., four strips from the BF tubes to 35°, 34°, 11°, and 5°, the last two then breaking; three strips from the C tubes to 74°, 72° and 36°; and four from the FF tubes to 12°, 11°, 9°, and 0°, the last breaking suddenly.

The other three steels stood the test as follows. after annealing. The G steel was bent to a semicircle at the crown of $\frac{1}{2}$-inch in diameter, when half of it broke through, the other half remaining perfect. The Bw was bent to an angle of 147°, when it began to yield in the center of the crown, the edges being perfect. The H was bent to a semicircle $\frac{5}{16}$ inch in diameter at the crown, when it broke half through. After tempering, the same metals only stood bending as follows: Five Bw strips to 11°, 8°, 6°, 4°, and 0°, all being broken through; four G strips to 40°, 16°, 0°, 0°, the last two breaking suddenly. The two H strips also broke without bending.

Of all the six brands, the Bw were the most uniform in temper and in grain of fracture, though hard; the C being the softest, while the BF, FF and G showed the greatest contrasts, especially in the appearance of their fractures. The BF and FF varied from fine to very coarse in grain, one edge of each being much coarser than the other. One of the G's was ductile and the fracture rather silky in appearance, the next was hard and fine in grain, the third hard but coarse in grain, and the fourth fine and silky at both edges, but laminated and dirty in the center. The annealed strip of the G was also remarkable; for, while it broke through halfway across long before the crown was hammered flat, the other half showed no signs of distress. In another case a strip of BF broke after bending

to 34°, when it exhibited a very coarse fracture; a second strip, cut from the same tube, bent only to 18°, and showed a fine steely fracture. It is certainly possible that these great contrasts may to some extent be due to want of care in the manipulation of the metals, and not entirely to want of uniformity in their composition: but it must be admitted, on the other hand, that such metals as will harden considerably when only moderately heated and plunged into water of ordinary temperature, are unfit for boilers, especially for furnaces and combustion chambers. It should also be remembered, that the tubes in question were made specially for testing, and it is therefore fair to suppose that more than ordinary care was taken to supply good material. In that case, what could be expected from tubes or plates supplied wholesale?

It is important to ascertain how far want of uniformity in composition has to do with local corrosion in metals, and particularly in steel; also how far the presence in a medium degree, or absence in a minimum degree, of impurities in iron and steel can affect their durability.

It may be observed that local corrosion cannot have been caused in any of the specimens of metals dealt with in this paper by the imperfect adhesion of their oxides, as, with the exception of the small pieces of plate tried in the Trusty, and the welded tubes, all the specimens were either planed, filed, or ground bright all over.

It has often struck the author that the manufacturer and the chemist, in their anxiety to produce a metal containing the least possible amount of impurities, and thus to attain a high standard of ductility, in depriving it, perhaps to a greater degree than necessary, of elements such as phosphorus, carbon, &c., or adding to it manganese, probably thus render it more liable to corrosion. If the metals tested in sea-going boilers be compared (the results are given in Table VIII.), it will be found that the ordinary BB Staffordshire iron has a percentage in its favor of 9.6 over the best Yorkshire iron, and that the harder steel, J, is 20.9 per cent. better than the two mild steels, N and Y. Comparing the two irons with the two mild steels there is a difference of 21.3 per cent. in favor of the irons. On the other hand, it should be mentioned that in one or two cases the harder metals suffered considerably more than the softer metals in sea water; but generally the reverse was the case. In the irons laminations and cinder, no doubt, caused these exceptions, but in the steels they were in all likelihood due to want of homogeneity.

It will not be out of place to give the results of the trial of three of these sets of plates to show how great the differences were between the loss sustained by one or more of the metals compared with others of the same set (see Table XI.)

The thirty-first set of plates was in one of the boilers of the Duke of Sutherland, a Holyhead boat belonging to the London and North-Western Railway Company; the time occupied was the longest of all the ocean experiments, namely, two and a half years. This vessel has two iron and two steel boilers; and as they are about five years old, and as the steel was manufactured at the company's works at Crewe, it would be interesting to know how the steel boilers now compare with the iron boilers.

In set 78 the Yorkshire iron DD shows a loss a little over twice that of the hard steel J; but in this instance the iron indicated plainly that a thin layer at the edge of one side, no doubt the result of lamination, had got disengaged, or corroded through. Again, in set 91 the hard steel J lost nearly 35 per cent. more than the mild steel N, and the soft iron DD lost 26.3 per cent. more than the hard iron BB.

The tensile test of the irons and steels supplied by the firms from whom these plates were obtained are given in the appendix, Table 2. Though the pieces tested were not from the same plates as some of those tried in the boilers, the results, coupled with those since supplied, furnish a fair idea of the softness or ductility of those metals, and may bear some relation to the losses sustained by them.

Turning again to the results of the tube experiments given in Tables I., II., and III., it will be observed that the four Fs ordinary tubes only lost 311.19 grains per square foot of surface, whilst the twelve, consisting of A1, D and E

TABLE XI.

Number of sets.	Letter marked with, and kind of metal.	Total loss of weight.	Average loss per square foot of surface.	Percentage in favor of the—
		Grs.	Grs.	
31	J. Crucible steel.....	2,027.5	7,704.5	
31	N. Bessemer "	2,630.2	9,994.7	
31	Y. Siemens "	2,437.3	9,261.7	Irons = 104.3
31	B.B. Staffordshire iron..	1,085 0	4,123.0	
31	D.D. Yorkshire " ..	1,230.1	4,674.3	
78	J. Crucible steel.....	657.9	2,500.0	
78	N. Bessemer "	839.4	3,189.7	
78	Y. Siemens "	718.1	2,728.7	Steels = 51.4
78	B.B. Staffordshire iron..	891.6	3,388.0	
78	D.D. Yorkshire " ..	1,344.6	5,109.4	
91	J. Crucible steel.....	124.5	473.1	
91	N. Bessemer "	92.3	350.7	
91	Y. Siemens "	111.6	424.0	Irons = 18.5
91	B.B. Staffordshire iron..	81.6	310.1	
91	D.D. Yorkshire " ..	103 1	391.7	

tubes, specially prepared, lost 691.68 grains, the difference being 122.2 per cent. in favor of the former. Again, whilst the four A 1 tubes named "Improved metal" lost 596.53 grains per square foot of surface, the E tubes called "Improved Homogeneous Metal," by far the most ductile and expensive of the two, and made by the same firm, lost 782.07 grains per square foot of surface; the difference in favor of the coarser metal being 31.1 per cent., the conditions of working being the same. On looking at the results of the cold-bending test of the "Improved Metal"—the coarser of the two last-named—it appears that while two of the pieces were doubled and hammered together flat without showing any signs of distress, the third began to give way when bent to 26° only. So great was the difference that it was hard to believe that the tubes were manufactured by the same firm and as of one brand.

Recent analyses of some of the brands of metal under consideration confirm the conclusions the author has drawn from the results of these experiments, viz., that the commoner sorts of iron, containing the most phosphorus, resist corrosion far better than the superior kinds; and also that the harder steels, containing the greatest amount of carbon and phosphorus, are better in this respect than the softer and finer sorts.

In the cruder classes of iron the percentage of phosphorus appears to range from 0.20 to 0.21, while in the better sorts it ranges from 0.07 to 0.14 In the milder steels it varies from 0.16 to 0.04 only. The percentage of carbon appears to be much about the same in all irons, varying only from 0.0545 to 0.074, while in the mild steels it ranges from 0.131 to 0.273. From 0.0649 to 0.1080 per cent. of manganese is found in the irons, and from 0.238 to as much as 0.75 per cent. in the steels.

Taking three brands of iron and three of steel, it appears that while the total amount of carbon in 3 tons of the irons, 1 ton of each brand, amounts to only 4 lbs. 1½ oz., in a similar quantity of the steels it amounts to 14 lbs.; and that while 3 tons of the irons contain 10 lbs. 1½ oz. of phosphorus, the same quantity of the steels contains only 2 lbs. 0¾ oz.

It would seem, therefore, that much yet remains to be done, both by the manufacturer and the chemist, in order to produce a metal possessing strength and ductility, but at the same time much better able than the present mild steel to resist corrosion. On the other hand,

the treatment of boilers might be so modified, especially with the aid of zinc properly applied, that the purer metals might be used for their construction without suffering the severe corrosion to which they are now liable.

With regard to the experiments quoted in this paper, it may be said that more definite results would have been obtained from more extensive trials; but to this it may be replied, that all experiments in which the conditions are not precisely similar cannot be considered satisfactory. Even when a steel boiler is worked side by side with an iron boiler, and is treated as nearly as possible in the same manner, causes arise, and will arise, to make the conditions somewhat different and the results unsatisfactory. And again, there is the difficulty in such matters of obtaining reliable evidence from mere observations, however carefully and honestly they may be made. Therefore it is contended that for cases such as have here been dealt with, and especially for short periods, the weighing scale is by far the most truthful means of ascertaining results.

The author has made a point in this paper of giving facts, and not indulging in assumptions and theories; in discussions on this important subject, there has hitherto been too great a tendency to follow up fanciful opinions, and to disregard ascertained facts.

Before concluding, mention may be made of the composite boilers constructed by the Admiralty in accordance with the recommendations of the late Boiler Committee. The shells of these boilers are of alternate rings of iron and steel, and in each there is a steel and an iron furnace. In one boiler the front end and the front tube-plate are of iron, and the back tube-plate of steel; in the other boiler the reverse is the case. Two sets of two each were made, but unfortunately much delay ensued before they were sent to sea. It will be admitted, setting aside the galvanic action theory, that this is a thoroughly practical experiment, and well worthy of careful attention. Perhaps it would have been still better if the iron shell-plates had been of a brand in ordinary use, and not of the best Yorkshire iron. The furnaces and combustion chambers would have been quite sufficient to test the latter metal against steel. Two of these boilers have now been about three years in commission, and it would be interesting to know their present condition.

For the courtesy always shown by the Engineer-in-Chief of Her Majesty's Navy, and the assistance rendered by the Secretary to the Boiler Committee to the author in the preparation of this paper, especially with regard to the ocean-plate experiments, he takes this opportunity of tendering his best thanks.

SANITARY DEFECTS IN HOUSES.

From "The Building News."

At the Parkes Museum of Hygiene, Dr. Charles Kelly, of Worthing, delivered an address upon the connection between zymotic disease and the sanitary defects in houses. He began by saying that the sanitary defects in houses which caused disease were those which permitted sewer gas to pollute the air or water of a house. Taking his instance from a south coast town, the author traced outbreaks of various zymotic diseases that had occurred during the last few years, and showed that although many of them were due to the milk or water supply some could undoubtedly be attributed to sewer gas, which found its way into houses where the sewers were unventilated. In some cases the ventilation of sewers had proved the cause of evil by the sewer gas escaping from the street ventilators, especially where the outfall of the sewer was tide-locked. This was shown by outbreaks occurring directly a new system of ventilated sewers had been laid down in a place where they had previously been without either regular house drains or sewers. The lecturer gave instances of enteric fever arising from polluted water, which had received the pollution from one person. In these

cases the houses were well ventilated, had a good soil, and the drainage was good; the water supply was the sole cause of nearly 30 persons having the fever. Another outbreak of fever occurred in a place with all sanitary requirements, with the exception that there were openings from the sewers, and those exposed to the air from these openings had enteric fever. This fever, he said, apeared sometimes to arise without imported cases. Some persons thought that there must be an imported case when the fever broke out, but careful inquiry would show that it frequently broke out without there being any prior case. It did not come so much to cottages as to the first-class houses, where the drain pipes were brought into the houses, and hence it was that the people who lived in cottages did not have this fever so much as those who lived in pretentious houses. Though not thought to be catching, yet, treated in close houses, it undoubtedly did spread. Outbreaks of scarlet fever in connection with defective houses exposed to sewer gas had frequently occurred. Diphtheria, again, was a disease which seemed to be in some cases due to sewer gas; but he had little doubt that cold and damp were predisposing causes in many cases, if not the origin. Besides the more severe forms of disease, there were other disorders due to sanitary defects which made little or no impression upon the death rate, but yet which affected the general health. Persons exposed to sewer gas in a dilute form were pale and anæmic; they often suffered from headache, sore throats, and from diarrhœa; the appetite was impaired, and they fell into a feeble state of health. Women and children were more liable than men, because they lived more at home, and are therefore more exposed.

To prevent the occurrence of these diseases, of which enteric fever may be taken as the type, it is essential: (1) That the drinking water should be pure; (2) That no sewer gas should enter the dwelling. Water, though delivered pure by a company, might become polluted in various ways after it has entered a dwelling. To prevent such pollution regulations were now laid down by most companies. If the constant system was in use all the drinking water should be drawn from a tap direct from the main; if the intermittent system was in use there should be a separate cistern for drinking water, and this should have no connection with any drains whatever. An overflow or wastepipe should not be attached to any cistern; but, as a precaution against overfilling, a tell-tale or warning pipe should be fixed, discharging in the open air. Every closet supplied with water should only be so supplied by means of a cistern, by which about two gallons of water could flow at each discharge. The supply pipe should not be less than $1\frac{1}{4}$ in. in diameter, so that the water must descend as rapidly and in as straight line as possible. To prevent the entrance of sewer gas it was needful that all sink and bath pipes should deliver into the open air outside the dwelling; their course should be as short as possible, and in many cases the pipe would only have to pass through the wall-sink or bath. The contents would then pass into a trap or gully about $1\frac{1}{2}$ ft. distant from the house-wall, so that if any gas happened to be forced through the trap it would pass into the atmosphere, and not into the house. The soil pipe should be outside the house, and from its upper end there should be a ventilating pipe carried up above the eaves of the dwelling. Some recommended that between the house drain and the main sewer there should be an intercepting trap so as to prevent the foul air, as from public sewers, from making its way into house drains. Two untrapped openings should be made in the drains so as to provide for a free circulation of air. In the model by-laws two methods were given for ventilation of house drains, but in all cases a trap was placed between the house and the sewers. Dr. Kelly said he was not sure that this plan was a good one. It made no provision for the ventilation of the main sewer other than by openings at the street levels. There was no statutory power to erect ventilating shafts by the side of houses without the leave of the owners, and such leave was not often given. In sea-side towns where the sewer was tidelocked twice a day, or in places where the sewer was laid nearly level, the means of ventilation by openings in the road was not sufficient. In some towns where these ventilators

were very offensive enteric fever had been found to be on the increase during the last two or three years.

Every house drain should be directly connected with the sewer so as to do away with any disconnecting chamber or trap. Every soil-pipe being carried up above the house in its full diameter, would then act as a ventilator to the main sewer. In a street half a mile long with houses on each side there might be as many as 150 or 200 ventilators, instead of only having eight or nine on the road level. Sewer gas was often less injurious than the air which was met with in the house drains if they were not well flushed. Any traps or contrivances which hindered the rapid flow of sewage were dangerous to health. That house could alone be considered fit to live in which within its four walls or beneath its basement contained no drains whatever. In many a village enteric fever was unknown, unless it happened to be imported. But in houses where the sanitary arrangements were very complex illness was frequently met with. In most places it was far healthier to live in a clean, well-built cottage, with no drains whatever, than in more pretentious dwellings where the drains were too often defective. In the simplicity of their dwellings the poor enjoyed an immunity often denied to the rich.

FRENCH METHODS OF CALCULATING THE PRESSURES IN AN ARCH.

By E. SHERMAN GOULD, C. E.

Written for Van Nostrand's Magazine.

In a previous paper (December No. of *Van Nostrand's Magazine*) I gave some of the routine methods employed by French constructors in building arches. These methods give results which, as far as design is concerned, can be guaranteed, for they are, in fact, nothing more nor less than precedent reduced to formulas. But this is by no means to say that arches built upon lines other than those therein laid down are necessarily defective.

In order to establish a test by which any given design for an arch may be tried as regards its strength, many able and well qualified men have labored to investigate the *theory of the arch*, for the purpose of deducing rules by which the strains in the various parts of an arch may be calculated, and the proper proportions of the structure determined.

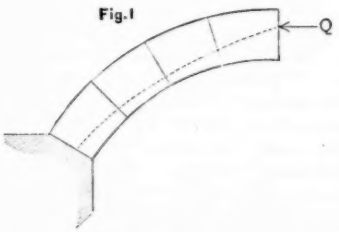
The calculation of the stability of masonry arches is frequently spoken of as if the subject were one admitting of the application of rigorous mathematical principles. Such, however, is not the case. When dealing with the strains in girders, trusses, and the like structures, composed of elastic materials, we know with a fair degree of determinateness not only the amount and distribution of the weights, but also the lines along which their strains are transmitted to the abutments; while in the reaction of the abutments, given in degree, direction and position, we possess a sure starting point from which all the other reactions may, step by step, be traced.

In the case of the vousssoir arch, the problem loses its determinate character. We know, indeed, the amount, position and vertical line of action of the weights of each voussoir, but this is all. We can not even tell how the surcharge is distributed, and it is often difficult to say, in this respect, which is the side of safety upon which to err, for the stability of an arch depends upon its *equilibrium;* and if we assume a system of distribution, or a degree of weight, which does not actually obtain, we may thereby be led to reckon upon a balance of pressures which does not exist.

Some idea of the difficulties which beset this subject may be gained from the fact that the efforts of the many distinguished men, who for the last 150 years have lent their talents to the task, have so far failed in eliminating the indeterminate character from the problem, and

so establishing the true theory of the arch. Their labors have not, however, been wholly fruitless, for many important principles have been developed. Among the most valuable contributions to our knowledge of the matter are the experimental researches of Boistard, who demonstrated the fact that the tendency of all arches, with their abutments, is to yield by breaking into four principal masses, and rotating around the five ensuing points of contact. Unless the arch be in perfect equilibrium, in which case the pressure is uniformly distributed over the faces of the joints, there is always a shifting of the center of pressure at these points, even when the joints do not in the least open, and it is principally owing to the impossibility of accurately locating the position of the center of pressure that the problem of the arch lacks determinate character.

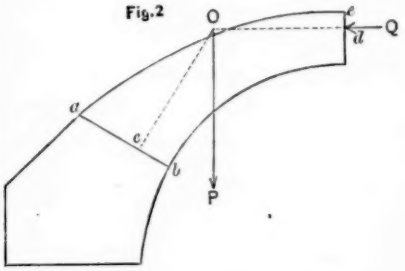
Of all the practical methods proposed as approximate solutions, that of Méry, known as the *curve of pressure*, is the one which, in France, has been received with the most favor, for, since its announcement in 1840 to the present day, it has, with various modifications, been almost exclusively employed in the designing and testing of arches in that country.



Before describing this important method in detail, it will be well to glance at its underlying principles. Let Fig. 1 represent the half of a segmental arch, kept from falling forward by the horizontal thrust Q. If the arch were complete this thrust would be furnished by the reaction of the other half, which we now supposed to be removed. If we knew the *amount* and *point of application* of the thrust Q, the simple graphic process of combining the same with the weights of the successive voussoirs, would enable us to obtain at once the *curve of pressure*, shown by the dotted line.

As regards the *amount* of Q, this element might be determined by the formula of Navier, to be described further on, but, as we have just seen, unless the arch be in perfect equilibrium, there is a tendency, slight or marked, according as the arch approaches or recedes from a state of perfect equilibrium, to open at the crown, and this causes the *point of application* of Q to rise or fall vertically along the face of the (imaginary) joint at the center.

Again, let Fig. 2 represent a half arch, and let *ab* be the joint of rupture (see article in December No. of magazine). Let P represent the weight of the mass situated above the joint of rupture, passing through its center of gravity, and Q the horizontal thrust. The mass above *ab* is held in equilibrium by Q, P, and the



reaction of the joint of rupture along *o c*. Of these three forces we can easily determine P in degree and position. If we knew the points of application *c*, *d* of the other two, a simple calculation or graphical construction would give us at once the value of Q in terms of P, and the curve of pressure could be accurately described.

But the same tendency exhibited by the thrust Q to concentrate itself at some point other than the center of the joint at the crown, is repeated by the component *o c* at the joint of rupture *a b*, so we are equally unable to fix the position of the point *c*.

In order to give determinateness to the problem, it is necessary to fix, arbitrarily, the position of the points *d* and *c*. M. Méry places the first at the distance *e d* from the extrados, equal to one-third of the depth at the crown, and the second at the distance *c b* from the intrados, equal to one-third of the joint *a b*. He

does so, from the following considerations: He assumes that the horizontal pressure at the crown is *nil* at the intrados, and that it increases in arithmetical progression, reaching a maximum at the extrados. The total pressure is therefore represented by the area of a triangle constructed upon the vertical joint, with its apex at the intrados. The resultant passes through the center of gravity of the triangle; hence the point d is at $\frac{1}{3}$ of the altitude of the triangle, measured from the base. Reasoning in the same way for the joint of rupture, the maximum pressure being here at the intrados, the point c falls at the distance $cb = \frac{ab}{3}$ from b. To ascertain if the thickness at the crown is sufficient to resist the pressure of the thrust, he assumes that $\frac{2}{3}$ of the total pressure is sustained by $\frac{1}{3}$ the depth at the crown. In other words, he assumes the keystone to be subject to a strain double of what would be produced if the pressure or thrust was evenly distributed over the whole depth. And the same way for the pressure upon the joint of rupture. As this assumption magnifies the actual strain—provided the points c and d fall where Mons. Méry places them—we may accept it with safety.

Of this method and its use the shortest criticism is the best. It is founded wholly upon undemonstrable assumptions, but as it invariably leads to dimensions which practice proves to be sufficient, and is moreover of an extreme simplicity in its application, the wisdom of the French engineers in adopting its use is fully justified.

In order to make this important method quite clear, I will work out an example by it. For convenience I take an example from Dubosque, in which the measures are given in French units. Fig. 3 shows half a full-centered arch, span 10 meters, rise, consequently, 5 meters. As it is not necessary that the real voussoirs enter into the calculation, we divide it so that a joint occurs at the center. The weights of the fictitious voussoirs above the joint of rupture are 2,820 kilos., 3,500 kilos., 4,875 kilos., and 5,500 kilos., as shown in the figure passing through their respective centers of gravity. Their total weight is 16,695 kilos., which passes through the center of gravity of the whole mass above the joint of rupture. It must be borne in mind that, the French unit being the meter, we are now dealing with a slice 3.28 ft. thick, instead of 1 ft. only, as would be the case if we were working in English measures. Hence the greater weights.

The depth of keystone is 0.80 meters (Dubosque uses Desjardin's formula).

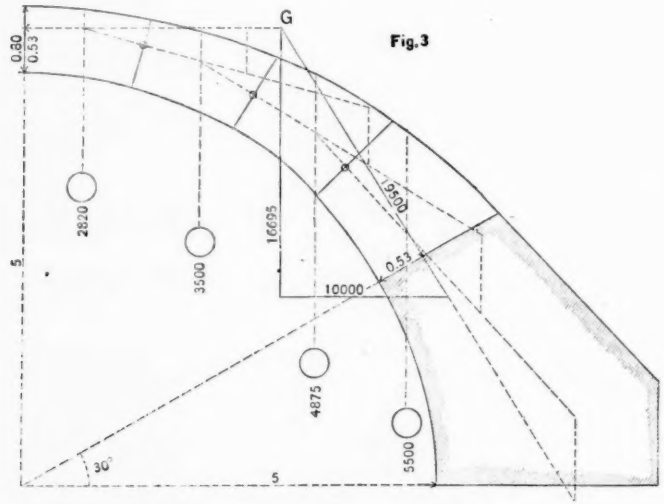


Fig. 3

Length of joint of rupture, 1.60 meters. Passing the horizontal thrust through a point 0.53 meters ($=\frac{2}{3}$ of 0.80) from the intrados at the crown, and producing it till it cuts the vertical line in G, and joining G with a point in the joint of rupture distant 0.53 meters ($=\frac{1}{3}$ of 1.60) from the intrados, we may readily construct the triangle of forces shown in the figure, having sides proportional to the weights 16,695, 10,000, and 19,500 kilos. All the rest of the work is sufficiently apparent from the figure, where the points at which the curves, or rather the broken lines, cuts the joints are marked by little circles. It is usual to commence at the crown, combining the horizontal thrust with the weight of the first voussoir at the line passing through its center of gravity. We could, however, just as well commence at the joint of rupture, and combine the oblique resultant with the weight of the voussoir next above the joint of rupture. Also the curve may be continued below this joint, down through the entire abutment, if desired.

This example is certainly that of an exceedingly well-conditioned arch, and there is no need to test the dimensions, either of the key or of the joint of rupture. If, however, in verifying the proportions of any given arch, we should find the curve of pressure to approach very closely to the extrados or intrados at any point, we should be obliged to see if the area comprised between the curve and the nearest bounding line of the arch was sufficient to bear the strain of $\frac{2}{3}$ of the entire resultant pressure at that point. Thus supposing, merely as an illustration, that we feared the curve approached too near the intrados at the joint of rupture, the resultant passing through this point is 19,500 kilos, two-thirds of which are 13,000 kilos. The area sustaining this pressure is $100 \times 53 = 53{,}00$ square centimeters, or 2.5 kilos., nearly, per square centimeter, or not quite $35\frac{3}{4}$ lbs. per square inch.

There is another, quicker way of getting the horizontal thrust. This is by the rule of Navier, already referred to, which reads that, in an inch *in equilibrium*, the horizontal thrust at the crown is given by the product of the radius of the curve of the intrados *at the crown* into the weight upon the unit of surface at the crown. The thrust thus obtained can be placed at the upper third of the depth of keystone, as before, and the curve worked out, as already shown.

This rule is often used by French engineers. At first sight it would seem a very bold jump at a conclusion, for it sets out by assuming the arch *to be* what we want to ascertain *if it is*. But it must be borne in mind that the whole investigation rests upon assumptions, more or less plausible, and that the tendency of a loaded arch, or of one in which the thickness is progressively augmented from the crown to the haunches, is to approach the form of equilibrium, so the assumption is not so audacious as would at first appear. It is certainly a very convenient rule, and is probably a very near guess at the truth, in a large majority of cases.

Let us apply it, for instance, to the example just worked. Taking the average weight of a cubic meter of masonry at 2,500 kilos. we would have for the weight per unit of surface at crown,

$$0.80 \times 2{,}500 = 2{,}000 \text{ kilos.}$$

Multiplying this by the radius, 5 meters, we have,

$$5 \times 2{,}000 = 10{,}000 \text{ kilos.}$$

Exactly what we found by Méry's method.

It would be a very interesting and instructive exercise to test a number of arches of different forms by the two methods. It must be borne in mind that the *radius at the crown* is what is used. In full-centered and segmental arches, this is the radius with which the intrados is struck. In basket-handled arches it would be the radius of the central arc. In elliptical arches the proper radius can be found by trial.

It will be observed that all of the above applies only to the arch proper, without extrinsic load or surcharge. When the surcharge is to be taken account of, it is necessary to combine it with the weights of the voussoirs, individually and collectively, which leads to a somewhat troublesome research of the centers of gravity.

A surcharge introduces an additional confusing element into the calculation, at least in many cases. When it consists of a bank of earth it is customary to consider such bank as devoid of cohesion, and pressing vertically downward over the whole extent of the horizontal projection of the arch. If this assumption

were correct there would certainly be in the case of a very high bank, an immense crushing strain upon the masonry, but on the other hand, the arch could not yield except by direct crushing, for one part, the crown for instance, could not sink without a corresponding rise at the haunches, which would be prevented by the immense weight upon them. Now, we know there are cases where the crown of arches so loaded settles, which would seem to prove that compensating pressure on the haunches must be wanting. The question would seem to depend upon how far the earth "arches itself," and how large a mass on each side of the center tends to detach itself and press upon the arch.

It would be repeating a twice-told tale to reiterate here the fact that the main cause of failure in an arch is the settling or spreading, or both, of the abutments. If these can be prevented from moving, either vertically or horizontally—and by "abutment" we must in this case understand everything below the line of rupture—arches of very slight dimensions can sustain surprisingly heavy loads without altering their shape, and their safety and rigidity will be then found to depend upon *workmanship* rather than *design*.

NOTE ON WEYRAUCH'S "VARIOUS METHODS OF DETERMINING DIMENSIONS."

By WM. CAIN, C. E., Charleston, S. C.

Written for VAN NOSTRAND'S ENGINEERING MAGAZINE.

In this Magazine for October, 1883, appears an article on determining dimensions taken from "selected papers of the Institution of Civil Engineers," in which the author, Professor Weyrauch, of the Polytechnic of Stuttgart, has given a résumé of many proposed formulæ for determining unit strains when the extremes of strain to which the piece is liable are given. In quoting me on p. 317, Weyrauch says: "for *alternate tension and compression* Cain simply makes $\varphi=0$." This is a mistake, for I did not mention this case in the article in this Magazine for November, 1877, referred to, and in a subsequent series of articles on "Maximum Stresses, &c." (Science Series, No. 38), I used "the American method," as Professor Weyrauch styles it, which I still think about as sound and practical as any proposed. If the reader will compare the results given on p. 393 of the issue of November, 1883, he will notice that the American method does not differ in the results so largely from the purely theoretical formulæ as to cause us to change our practice, even if the latter were based on more correct data. However, as these data are of the most meager kind the formulae can hardly be said to be based on any experimental data; therefore, we shall pass on to the case of simple tension or compression.

For this case, singularly enough, the last theoretical speculation is based on ideas advanced before Wöhler's experiments were made, *i. e.*, that a suddenly applied load causes twice the increase of stress due to the same load gradually applied.

In a paper presented by Messrs. John Griffen and Thomas C. Clarke to the American Society of Civil Engineers, June 5, 1872, this very principle, as deduced in mechanics, was used in the rule proposed—"multiply the live load by two and add it to the dead load," and treat the sum as dead load alone. Clericetti (Vol. 29, No. 5) starts with this assumption, and first shows the principle to agree with Wöhler's results, but to differ very greatly from the English experiments mentioned. He then deduces very easily *the stress per unit of area* (by dividing the sum of live and dead loads by the cross section).

$$b_0=\frac{f}{2-\theta_0} \quad . \quad . \quad . \quad (1)$$

where θ_0=ratio of dead load to sum of live and dead loads, and f represents some stress less than the primitive strength that must be chosen to answer

the needs of practice. This formula agrees for certain constants with Ritter's and Lippold's. Gerber, in place of multiplying the live load by two, endeavors to ascertain from Wöhler's experiments the factor to multiply by, but it is plain that these experiments are on too small a scale to decide this matter; in fact, they do not agree with the English experiments.

The formula proposed by the writer in *Van Nostrand's Magazine* for November, 1877, is,

$$b=7500(1+\theta) \quad . \quad . \quad . \quad (2)$$

Here b=stress in pounds per sq. in.,
And, θ=ratio of smallest strain the piece ever bears to the greatest.

This is a modification of the Launhardt Weyrauch formula that is supposed to allow for impact.

If, in formula (1), we make $f=15{,}000$, the extremes of safe unit stress for $\theta=0$, or $\theta=1$, are the same by formulae (2) and (3).

$$b_\theta=\frac{15{,}000}{2-\theta_\theta} \quad . \quad . \quad . \quad . \quad (3)$$

b is here expressed in pounds per square inch. Neither of these formulae, (2) or (3) are correct, nor agree with all the experiments that have been made; besides they are based upon different principles, yet the form of both is simple, both aim to include the effect of impact, and both embody Wöhler's law—that the minimum strain sufficient for rupture *decreases* as the difference between the extremes of strain to which the piece is liable *increases*. Hence, I thought that it would be interesting to compare the results.

Thus, assuming the values of $\theta=\theta_\theta$, as in the table below, drawn from the article quoted (in the November, 1877, issue of this Magazine), we deduce for trusses of various spaces the following values of b and b_θ for the lower chords:

Span.	$\theta=\theta_\theta$	b	b_θ
10 ft.	0	7,500	7,500
100 "	$\frac{2}{3}$	9,325	8,540
200 "	$\frac{3}{4}$	10,300	9,230
300 "	$\frac{4}{5}$	11,250	10,000
400 "	$\frac{5}{6}$	12,190	10,910
Dead load only.	1	15,000	15,000

The Weyrauch formula would give, if the constant is so chosen, $b=15{,}000$ lbs. per square inch for dead load only, and $b=10{,}000$ lbs. for $\theta=0$, and intermediate values for other values of θ. I submit that the extremes are not great enough for practice, which is to be accounted for from the fact that the Weyrauch formula is deduced directly from Wöhler's experiments, and does not otherwise, even empirically, include impact.

When we go to the web members of a 200-ft. span Pratt bridge, Weyrauch's formula gives as the safe strain for counters 10,000 lbs. per sq. inch, and for the end ties 11,750 lbs. per square inch; whereas formula (2) above gives for a 16 panel truss, the safe unit stress for ties:

in 1st	panel....	10,000
2d	"	9,940
3d	"	9,780
4th	"	9,460
5th	"	8,900
6th	"	7,950
7th and 8th	"	7,500
Counters		7,500

In this computation the *maximum strain* on tie was found for load extending from farthest abutment to foot of tie, *the minimum* when load extends from nearest abutment to top of tie. without entering into the computation of strains from dead load alone, the minimum to be used in the value of θ_θ in formula (3) it is plain that whilst the values by (3) would still differ from those just given, yet the differences would not be so great as in the case of the chords, where the minimum strains in both cases are due to dead load only.

Considering the totally different deviation of the formulae, the difference in the values is not so great: so that in practice either formula could be chosen, and form the basis of any short rules that might suggest themselves.

The formulae have this to recommend them; that they are systematic, partly based on experiment, aim to include impact, and embrace Wöhler's law.

It is plainly indefensible, as Weyrauch says, to disregard this law, for experiments and experience both sustain it.

Now, although American engineers acted on this principle in certain cases before the law was even derived by Wöh-

ler, yet it has not been uniformly applied. Thus, I am not aware of the first specification where b for web members is made to vary from panel to panel according as the difference between the extremes of strain of the piece changes as we go from panel to panel.

Generally all, or nearly all, of the main ties are designed for the same maximum unit stress, though it is very easy to specify a varying stress in accordance with Wöhler's law. None of the formulae yet proposed are accurate, as Weyrauch says, for the actual conditions met with in practice. So that, if engineers decline to follow any of the formulae strictly, still some simple rule that gives results within the bounds of safety, and that follows Wöhler's law, should be used.

Thus, for any bridge, having given a unit stress for the lower chord and the main ties at the end, also another unit stress for the counters and middle ties, then make the unit stress on the intermediate ties increase regularly from the first panel where a counter is needed to the end panel.

Thus, in the example just given, the 7th is the first panel requiring a counter, so that, subtracting 7,500 from 10,000, and dividing by 6, we get 417, the common difference, from whence we find, by addition, for 6th panel, $b = 7{,}917$

5th	"	$= 8{,}334$
4th	"	$= 8{,}751$
3d	"	$= 9{,}168$
2d	"	$= 9{,}585$
1st	"	$= 10{,}000$

These unit stresses are all less, by several hundred pounds than those given above by the formula, $b = 7{,}500(1 + \theta)$, so that the results are *safer*, at least, than by this formula, and approximate those given by the other formula (3).

Crude as this method is, it recognizes Wöhler's law, and is better than the old method. For very large bridges, especially, there is such a large difference between the unit strains given the end web members and the counters, that it is totally inconsistent not to vary the unit strains on the intermediate web members in some fashion.

Where other styles of truss, as the Fink, bowstring, etc., are used, the simple rule suggested above cannot be used, but a resort to some formula involving maximum and minimum strains is necessary. In fact some formula or formulas of this kind must form the rational basis of any short rules, not simply for bridge members, but for the computation of the sizes of pieces in any structure or machine whatever.

ECONOMY OF STEAM POWER AT WORKS OF NATIONAL RUBBER CO., BRISTOL, R. I.

By JOHN W. HILL, M. E.

Contributed to VAN NOSTRAND'S ENGINEERING MAGAZINE.

THE following paper is a resumé of a series of investigations made by the writer during the months of August and September, 1883, for the National Rubber Co., at Bristol, R. I., with a view to suggesting improvements in the steam plant, calculated to increase the economy, and comprehending a general examination of all the principal appliances for making and using steam in the works.

The Works of the National Rubber Co.—the largest of the kind in the United States—cover more than forty acres of ground, employ over two thousand operatives, and consume for power and steam-heating purposes alone upwards of sixty thousand dollars worth of coal per annum.

To reduce this coal consumption by well-advised changes in the plant, was the object of the experiment: the results of which are given in narrative form in the following paper.

The investigations embraced the following machinery:

North Boilers.—Steam used for curing rubber goods. heating north building, driving small engine, furnishing power to the sewing machines, and driving elevator engine.

Main Boilers.—Steam used for curing rubber goods, heating rolls and presses, driving 36″ × 72″, condensing engine, driving 26″×48″ and 28″×48″, non-condensing coupled engines, driving 10″× 24″ non-condensing machine-shop engine, driving feed pumps and fire pumps and heating buildings.

Pump House Boilers.— Furnishing steam to 1,000,000 gallon Worthington Compound Duplex Pumping Engine.

Harris Corliss' Condensing Engine.— Furnishing motive power to machinery of new works.

Harris Corliss' Non-Condensing Coupled Engines.—Furnishing motive power to machinery of old works.

Harris Corliss' Non-Condensing Engine.—Furnishing motive power to machine shop and box factory.

Worthington Compound Duplex Pumping Engine.—Supplying sea water to the works.

The boilers in the North house and in the Main house were tested for economy in the following manner:

All water supplied during the interval of trial in each instance was carefully weighed in a large tank mounted upon a new Fairbanks' dormant scale, capable of weighing 3,500 pounds in gross. From the weighing tank the water was drawn into a supplemental tank connected with the suction of the feed pump, from which it was pumped as required into the boilers.

In the North house the feed water was taken from the return pipe, from the curing ovens and radiators. In the Main house the feed water was drawn from the city mains.

In order to check the quantities of water delivered to boilers during certain fixed intervals of time, the levels in the glass gauges were carefully read at beginning of trials, and at end of trials; and in all instances when the original levels were not fairly restored at end of trial, corrections have been made by adding or subtracting a weight of water equivalent to the volume in excess or short of true level at temperature of evaporation.

The feed water was tested for temperature just before its entrance to boilers, and in all instances where it passed through heaters it was tested for temperature before and after it passed the heater.

The coal burned during interval of trial was weighed in uniform charges of 300 pounds upon tested platform scale, and dumped as required in front of boilers. Trials were begun and ended with strong charges upon the grates and clean ashpits, and all ash, clinker and unburnt coal found in the ashpits at end of trials were weighed back and credited as non-combustible.

The temperatures of air in boiler-house, and hot gas passing in the smoke connection, were taken at regular intervals of fifteen minutes.

The steam pressure, temperature of feed to boilers, water levels, and pressure of atmosphere were read at regular intervals of fifteen minutes.

Calorimeter observations for quality of steam were made at regular intervals of fifteen minutes or half-hourly in the several trials.

In the trial of boiler at Pump house, the feed water supplied was measured in a large storm water tank, capable of carrying several days' supply, by taking levels at beginning and at end of trial, and at regular intervals of one hour, during the trial from which volumes (computed from differences of heads and known diameter of tank) the weight corresponding to observed temperatures was calculated. The coal for the trial at Pump house was weighed in uniform charges of 100 pounds and dumped in front of boiler as required.

In the test for economy of Harris Corliss' condensing engine the consumption of steam was measured by weighing the condensation as it was pumped from the condenser (surface) by the air pump.

The discharge of the air pump was conveyed through a tight rubber hose to the weighing tank previously mentioned for weighing feed water to boilers, and weighed for hourly delivery.

The quality of steam, meanwhile furnished by the boilers, being tested by calorimeter at regular intervals of thirty minutes.

Indicator diagrams were taken from each end of cylinder by Thompson indicators, set with short connections, at regular intervals of fifteen minutes. The steam gauge in pipe, engine counter, barometer vacuum gauge, and thermometers in injection, and overflow pipes, and hot well of condenser, and atmospheric thermom-

eter were read regularly every fifteen minutes.

In the test for economy of Harris Corliss' non-condensing coupled engines, and Harris Corliss' non-condensing machine-shop engine, the consumption of steam was measured by weighing the feed water to the plain cylinder boilers of Main house, all the evaporation of which was confined to the coupled engines and to the machine-shop engine during the interval of trial. The arrangement of steam pipes in the Main house is such that steam to the machine-shop engine could not be furnished independent of the main pipe supplying steam to the coupled engines, and as it was inconvenient to stop the machine-shop engine for a day at time of test, the latter was indicated for power during this trial, and an estimate was made of steam consumption upon precedents from engines, in similar condition and developing similar powers.

The feed water to boilers similar for this trial was reported in hourly quantities.

The data for quality of steam furnished by the boilers were taken half-hourly during trial.

Two Thompson indicators were used upon each cylinder of coupled engines, and a single Elliott-Richard's indicator was used upon the cylinder of machine-shop engine.

Diagrams from all cylinders were taken regularly every fifteen minuter.

The pressure in pipe and engine counter were read regularly every fifteen minutes.

In the tests of Harris Corliss' condensing and Harris Corliss' non-condensing coupled engines for distribution of power, the only data taken were the indicator diagrams which were lettered to correspond with the known machinery driven.

In the test of Worthington compound pumping engine, for capacity, the data taken were the heads at fixed intervals of time in the sea water tank in the factory yard, the engine counter connected with pumps for same intervals, and the length of the stroke made by plungers during the period of test.

In the test of same machine for duty the data taken were the pressures of steam in boiler, water in rising pipe, and of atmosphere in pump house, vacuum in condenser, engine counter, temperatures of injection, overflow and condensation from condenser, rise and fall of tide in the harbor, weights of coal and water supplied to boiler and quality of steam furnished by boiler, temperatures of waste gases from smoke connection temperatures of feed water to heater in smoke connection, and in feed pipe between heater and boiler, and water levels in boiler.

The tests of Pump house boiler for economy, and of Worthington pumping engine for duty, were made at one and the same time, but for convenience of reference of boiler performance to boiler performance in North and Main houses, will be reported separately.

North Boilers.

The North boiler house contains five return tubular boilers, set in independent furnaces, with independent feed water connections, and independent connections of steam spaces of boilers with two steam mains, one leading to the curing ovens, and one leading to the steam radiators in North building.

The boilers are provided with smoke extensions, from which vertical legs or uptakes lead into a horizontal flue of sheet iron running above and in front of boilers to the brick chimney. Each uptake is provided with an independent pivoted damper.

Each boiler is furnished with a pop-safety valve, steam gauge, glass water gauge, test cocks, and separate regulating cock and check valve in feed pipe.

The boilers were constructed by the Whittier Machine Co., Boston, Mass.

The following dimensions are taken partly from the contractor's drawing and partly from personal measurements.

Dimensions North Boilers.

Style	Tubular.
Number	5
Diam. of shells.....inches	48
Length " .....feet	14
Tubes.....number 60, diameter	3"
Grate	4'×4'
Heating surface each boiler....sq. ft.	747.701
Grate " " " .... "	16
Tube vent..... "	2.475
Ratio heating to grate surface	46.731
Ratio grate surface to tube vent.....	6.464
Total heating surface 5 boilers..sq. ft.	3738.5
Total grate surface 5 boilers... "	80
Chimney Height.....feet	101
Chimney cross section.....sq. ft.	12.25

Ratio total grate surface to cross section of chimney	6.53
Space over bridge wall, inches	12
" " grate " "	18.5

Of above boilers the four nearest chimney were tested together for economy.

The trials were made of these boilers upon the work of curing ovens.

The East boiler meanwhile running separately to furnish steam to the radiators and sewing machines engine.

The first trial, August 20–21, with maximum consumption of steam, represented the requirements of the nine (9) new curing ovens with open stop valves and maximum loss of heat by contact of air and radiation for subsisting temperatures of steam and air and oven walls, and as many of the five (5) old curing ovens as were then in use under ordinary conditions.

The steam to the elevator engine is taken from the same main which supplies the curing ovens, and this additional work, however slight, was upon the boilers (4) operated for economy.

The second trial, August 21, for economy under ordinary daily conditions of work, represents the requirements of so many of the five (5) old curing ovens as were in use at that time, together with steam consumption by elevator engine as before.

The coal fired was Cliffield, a mixture of bituminous nut and slack.

In the following table are given the principal data, averages, totals, and calculated results from the log of first trial.

FIRST TRIAL OF NORTH BOILERS.

Date of trial	Aug. 20–21
Boilers used	4
Heating surface, sq. ft.	2990.8
Grate surface, sq. ft.	64.

GENERAL OBSERVATIONS.

Duration of trial, hours.	16
Average steam pressure, pounds,	87.367
Average temperature of feed water to boilers	161.547=162.295
Average temperature of air in boiler-room, Fahr.	100.375
Average temperature of waste gases, smoke connection, Fahr.	345.20
Average temperature of waste gases, boiler extension, Fahr.	387.72
Barometer, inches,	29.943

CALORIMETER.

Average water heated, pounds,	200
Average steam condensed, pounds,	10.389
Average initial temp., Fahr.	77.444= 77.479
Average final temp., Fahr.	130.222=130.556
Average heat units per lb. of steam	1,152.643
Thermal units per pound of steam at observed pressure	1,214.28
Difference	61.637
Latent heat at observed pressure	881.87
Percentage of water entrained in the steam	6.989

TOTALS.

Total water to boilers, pounds,	91,473.000
Total water entrained in the steam, pounds,	6,393.048
Total steam furnished, pounds,	85,079.952
Steam per hour, pounds,	5,317.497
Total coal burned, pounds,	11,100.000
Total ash and clinker and unburned coal weighed back, pounds,	942
Percentage of combustible	91.514
Coal per hour, pounds,	693.75

ECONOMY.

Steam per pound of coal from temperature of feed water, pounds,	7.6648
Steam per pound of coal from and at 212 Fahr., pounds,	8.349
Steam per pound of combustible from and at 212 Fahr., pounds,	9.123
Steam per square foot of heating surface per hour, pounds,	1.778
Coal per square foot of grate surface per hour, pounds,	10.84

The trial of sixteen (16) hours was divided into two runs of eight (8) hours each, the day run to Hammack, and the night run to West, to compare the work of firemen.

No material change occurring between day and night in condition of coal, feed water, and steam consumption, the results for the separate runs are a very certain index of the comparative qualities of firemen. In the following table are given the necessary averages, totals and calculated results for day run by Hammack:

DAY RUN, HAMMACK, 8 HOURS.

Coal burned per hour, pounds,	675.00
Steam per hour "	5,522.53
Temperature of feed water, Fahr.,	163=163.773
Steam pressure, pounds,	91.46
Steam per pound of coal from temperature of feed water, pounds,	8.1815
Steam per pound of coal from and at 212 Fahr., pounds,	8.8998

In the following table are given the averages, totals and calculated results for the night run by West;

NIGHT RUN, WEST, 8 HOURS.

Coal burned per hour, pounds,	712.5
Steam per hour "	5,112.466
Temp. of feed water, Fahr.,	160.09=160.275
Steam pressure, pounds,	82.75
Steam per pound of coal from temperature of feed, pounds,	7.1754
Steam per pound of coal from and at 212 Fahr., pounds,	7.8327

It will be observed that the demands for steam were greatest by eight (8) per cent during the day run, with a difference of 3.5 degrees in temperatures of feed water in favor of day run. The difference in temperature of feed water day and night, is roughly 0.3 of one per cent or too small to affect the comparison if neglected entirely.

For the day run Hammack carried an average pressure of 91.46 pounds, with an evaporation (net) of 8.9 pounds of steam per pound of coal from and at 212 Fahr.; while West for the night run carried an average pressure of 82.75 pounds (a loss of 8.75 pounds) with an evaporation of 7.83 pounds of steam per pound of coal from and at 212 Fahr. With odds in favor of the night run, Hammack develops a better average performance by nearly fourteen (14) per cent.

Hammack's economy in this trial is good, and as a matter of note at the time, fired his coal with less exertion than did West during the night run.

The fires were cleaned one hour before Hammack left and West started, and the latter had the benefit of a pressure of 94 pounds to start with, and no unfavorable conditions calculated to make his economy inferior to Hammack's. The writer is of the opinion that West could scarcely be relied upon to push these boilers for maximum requirements with economy, but with two firemen the equals of Hammack in skill and assiduity, the boilers (4) can be worked to furnish all steam required for old and new curing ovens, under ordinary conditions, with an economy at least good, if not excellent. It is not possible to develop a high economy with these boilers subject as the log shows to great fluctuations in the demands of steam from hour to hour.

In the following table are given the averages, totals and calculated results for second trial of North boilers;

SECOND TRIAL NORTH BOILERS.

Date of trial	Aug. 21.
Boilers used	4
Heating surface, sq. ft.	2990.8
Grate surface, sq. ft.	64

GENERAL OBSERVATIONS.

Duration of trial	13 hrs. 45 min.
Average steam pressure, pounds,	98.86
Average temperature of feed water to boilers	153.87=154.496
Average temperature of air in boiler room, Fahr.	95.41
Average temperature of waste gases, smoke connection, Fahr.	313.86
Average temperature of waste gases, boiler extension, Fahr.	371.73
Average barometer, inches,	29.963

CALORIMETER.

Circulation per hour	8,819.81
Condensation per hour	352.4
Temp. of injection, Fahr.	71.563= 71.586
Temp. of overflow, Fahr.	114.809=115.013
Temp. of condensation, Fahr.	88.209= 88.276
Thermal units per pound of steam	1,175.160
Thermal units per pound of steam at observed pressure	1,216.700
Difference	41.54
Latent heat at observed pressure	876.00
Percentage of water entrained in the steam	4.742

TOTALS.

Total water to boilers, pounds,	39,009.2
Total water entrained in the steam, pounds,	1,849.81
Total steam furnished, pounds,	37,159.31
Steam per hour, pounds,	2,702.509
Total coal burned, pounds,	4,416.5
Total ash and clinker and unburnt coal weighed back, pounds,	533
Percentage of combustible	87.93
Coal per hour, pounds,	321.2

ECONOMY.

Steam per pound of coal from temperature of feed water, pounds,	8.414
Steam per pound of coal from and at 212 Fahr., pounds,	9.2554
Steam per pound of combustible from and at 212 Fahr., pounds,	10.5259
Steam per square foot of heating surface per hour, pounds,	0.9036
Coal per square foot of grate surface per hour, pounds,	5.0187

The trial of thirteen (13) hours and forty-five (45) minutes was divided into a day run of 7:45 hours for Hammack, and a night run of 6 hours for West, with the following results:

DAY RUN, HAMMACK, 7 HOURS 45 MINUTES.

Coal burned per hour, pounds,	286.516
Steam per hour, pounds,	2,587.083
Temp. of feed water, Fahr.	147.21=147.742
Steam pressure, pounds,	102.37
Steam per pound of coal from temperature of feed, pounds,	9.0294
Steam per pound of coal from and at 212 Fahr	9.995

NIGHT RUN, WEST, 6 HOURS.

Coal burned per hour, pounds,	366
Steam per hour, pounds,	2,851.58
Temp. of feed water, Fahr.	161.66=162.41
Steam pressure, pounds,	94.33
Steam per pound of coal from temperature of feed, pounds,	7.7912
Steam per pound of coal from and at 212 Fahr., pounds,	8.5056

In the comparison of Hammack and West for second trial the average hourly

demand for steam was ten per cent. less for the day run than for night run, and the difference in temperature of feed water 1.21 per cent. in favor of night run.

The results show Hammack's economy to be 1.75 per cent. better than West's; which corrected for difference of temperature of feed water, makes a gain of 18.75 per cent. for Hammack over West.

Although the demand for steam per hour was least during day run, the writer is not inclined to ascribe Hammack's extra economy to this cause; the rate of evaporation being too low for good economy during the whole trial, and the reduced demand for steam during Hammack's run being rather against than in favor of his economy.

Assuming the boilers to be run for one year at a rate midway between first and second trials, or with an hourly consumption of coal, based on Hammack's record, of 480.75 pounds, then the coal burned per day (24 hours) would be 5.769 tons, and for a year of 300 days, 1,730.7 tons, or a cost at $5.50 per ton, or $9,518.84, exclusive of coal required to start fires and raise steam Monday mornings; (which should be 1.25 tons, or 62.5 tons for entire working year of fifty weeks).

Under the same conditions, but estimating from hourly consumption of coal by West of 539.25 pounds, then coal burned per year of 300 days would be 1,941.3 tons, costing $10,677.15, exclusive of Monday mornings coal to raise steam, which would be no greater, and possibly less, with two firemen of Hammack's standard, than with two firemen of West's standard.

Assuming, however, that a new fireman be substituted for West, equal in efficiency to Hammack, then the annual saving to the Rubber Co., under conditions of work midway between the work of first and second trials, would be $579.15, this amount being the saving Hammock makes (by his record) over West.

Referring to the trials as a whole, the economy is fair considering the dimensions of boilers, but these are small for tubular boilers and should have been not less than 60 inches diameter of shell with 50—4″ tubes or 75—3″ tubes each.

Tubular boilers of less than 60 inches diameter of shell seldom give a high economy, from the fact that the shell is the most efficient surface, and the larger it is for a given length the more complete the absorption of radiant heat from the grate; more than 75 per cent. of the total steam is made by the heating surface of shell, and this surface, always consistent with safety, should be as large as possible.

An excellent change, however, would be the substitution of three boilers similar to the tubular boilers in Main house E G 6′ diam., 15′ long, with 100—3″ tubes each; by the latter change an improvement of 20 to 25 per cent. in the economy would be obtained, with ample heating surface for most exacting requirements.

The latter improvement should furnish the Rubber Co. a saving of $2,000 in round numbers in the coal bill per year for North house, a very handsome income for the investment represented by the three 72″ tubular boilers, besides the labor will be reduced by the fewer fires to manage, and the fireman should be able to wheel both coal and ashes with this arrangement.

The present stack is admirably adapted to the proposed change of boilers.

Main Boilers.

The boiler plant in the Main house consists of a battery of six tubular boilers, and four sections of sixteen plain cylinder boilers, the evaporation from which mingles in one system of distributing steam mains.

The tubular boilers are similar in general design to those of the North house, but are of larger dimensions, and set in independent furnaces, provided with independent uptakes and dampers, separate feeds, steam and water gauges.

The feed water is taken from the city mains, and pumped through a fuel economizer placed in the flue leading to the chimney.

The smoke connections of sheet iron pass aft over the boiler setting and bend down at rear end of brickwork into a brick flue, common to all the (tubular) boilers, and leading into the base of brick chimney.

The boilers are well designed and set and show a gratifying economy.

In the following table are given the dimensions of tubular boilers, taken partly

from the contractor's drawing and partly from personal measurements.

DIMENSIONS OF TUBULAR BOILERS.

MAIN HOUSE.

Style	Tubular.
Number	6
Diameter of shells ....inches	72
Length of shells....feet	15
Tubes	100—3″
Grate	6′1″×4′6″
Heating surface, each boiler....sq. ft.	1319.472
Grate surface, each boiler.... "	27.75
Tube vent.... "	4.125
Ratio heating to grate surface	47.548
Ratio grate surface to tube vent	6.727
Total heating surface, 6 boilers. sq. ft.	7916.832
Total grate surface, 6 boilers.. "	166.5
Chimney height....feet	113.5
Chimney cross section....sq. ft.	25
Ratio total grate surface to cross section of chimney	6.66
Space over bridgewall....inches	12
Space over grate.... "	27

Builder, Whittier Machine Co., Boston.

Two trials were made of the tubular boilers; the first trial owing to breaks in the record was unreliable, and a second trial was made with the following results. This trial represents the daily work of boilers as at date, August 27th, with no known changes either in the management of fires or in the consumption of steam from the daily average performance.

The coal fired was Cliffield, of the same quality as that used under the North boilers.

PERFORMANCE OF TUBULAR BOILERS.

MAIN HOUSE.

Date of trial	Aug. 27
Boilers used	6
Heating surface ....sq. ft.	7,916.832
Grate surface.... "	166.5

GENERAL OBSERVATIONS.

Duration of trial.... hours	10
Average steam pressure....pounds,	70.545
Average temperature of feed water to heate., Fahr...	66.4
Average temperature of feed water to boilers, Fahr....107.59=	107.746
Elevation of temperature by heater.	41.346
Gain by heater, per cent.	3.613
Average temperature of air in boiler room, Fahr.	95.050
Average temperature of waste gases in flue front of heater..	295.5
Average temperature of waste gases in flue behind heater.	333.1
Average temperature of waste gases boiler extension	318.600
Average barometer....inches,	30.214

CALORIMETER.

Average water heated....pounds,	200
Average steam condensed..pounds,	10.157
Average initial temp., Fahr. 74.286=	74.314
Average final temp., Fahr. 127.952=	128.264
Average heat units per pound of steam	1190.585
Thermal units per pound of steam at observed pressure	1210.33
Difference	19.745
Latent heat at observed pressure.	891.29
Percentage of water entrained in the steam	2.215

TOTALS.

Total water to boilers....pounds,	127,555
Total water entrained in the steam, ...pounds,	2,825.343
Total steam furnished....pounds,	124,729.657
Steam per hour....	12,472.967
Total coal burned....pounds,	12,361.00
Total ash and clinker and unburnt coal weighed back....pounds,	1,650.00
Percentage of combustible....	86.66
Coal per hour....pounds,	1,236.1

ECONOMY.

Steam per pound of coal from temperature of feed water..pounds,	10.091
Steam per pound of coal from and at 212 Fahr....pounds,	11.5208
Steam per pound of combustible from and at 212 Fahr...pounds,	13.2933
Steam per sq. ft. of heating surface per hour....pounds,	1.575
Coal per sq. ft. of grate surface per hour....pounds,	7.724

COAL FOR BANKING AND STARTING FIRES.

TUBULAR BOILERS, MAIN HOUSE.

Coal to start fires Monday, A. M., Aug. 27th....pounds,	6,839
Coal to start fires Tuesday, A. M., Aug. 28th ....pounds,	6,000
Coal to start fires Thursday, A. M., Aug. 30th....pounds,	4,246

The economy from above trial is excellent, and considering the fact that no exertions were made to improve the performance above the daily average, it shows a result seldom equaled and never to the writer's knowledge excelled. By this the writer does not mean to say that the economy is equal to the best he ever had, but in every instance, and the instances are rare, where better work has been done, it has been under "whip and spur" as it were, and not under the conditions of ordinary factory practice.

In brief, omitting special test trials, this is the very highest economy within the writer's experience, and exhibits an excellent proportion of boilers, a good setting, and a careful management of the fires.

The most important remark to be made in connection with this trial is, that it exemplifies an economy which should be made a standard, and which may be obtained in the North house by the change

of boilers previously suggested. The coal required to start fires Monday and Tuesday, August 27–28, is excessive, and represents a thickness of fire of six to seven inches over entire grate.

The coal used to start fires Thursday morning, August 30th—4,246 pounds—represents a fire four inches thick on whole grate, which is ample and should not be exceeded.

When small quantities of steam are required for power or heating buildings at night, it will be found much more economical to make it with one or two boilers and an active fire than with six or more boilers and a slow fire.

All boilers not in active use at night should have the fires banked, and ashpit doors, fire doors and dampers closed. If closing the fire doors with banked fires is calculated to make steam during the night, then the fire doors may be opened just enough to prevent this, but dampers and ashpit doors should be kept closed.

It costs nothing but vigilance to guard the avenues of loss in steam boilers, while it costs dollars to supply the losses if the means to prevent them are neglected.

After it has been determined how much steam is properly required of the main boilers, then the excess beyond a favorable capacity for the six tubular boilers should be made with more tubular boilers of same dimensions.

The plain cylinder boilers are arranged in three sections of four (4), one section of three (3), and a single boiler set in an independent furnace to burn the refuse from the box factory.

During the test for economy, coal was burned under the single boiler as well as under all the rest.

The glass gauges on these boilers were clogged with sediment, and the water levels were taken from the register gauge cocks.

Each section of boilers is furnished with its own feed connection, smoke connection and steam gauge, and a large drum set transversely over each section, collects the steam from the several boilers preliminary to its delivery to the distributing mains.

A long brick flue running transversely of boilers behind the setting collects the hot gases and delivers to the base of brick chimney.

In the following table are given the dimensions of the plain cylinder boilers.

DIMENSIONS OF PLAIN CYLINDER BOILERS.

Style	Cylinder.
Number	6
Diameter of shells, inches,	30
Length of shells, feet,	30
Heating surface, each boiler, sq. ft.,	117.801
Grate " " " " "	44.000
Total heating surface 4 boilers "	471.204
Ratio heating to grate surface "	10.709

One trial of these boilers was made using same quality of coal as before (for North boilers and Main tubular boilers) under the ordinary factory requirements, as at date Aug. 29th.

PERFORMANCE, PLAIN CYLINDER BOILERS, MAIN HOUSE.

Date of trial	Aug. 29
Boilers used	16
Heating surface, sq. ft.	1884.816
Grate surface " "	176.

GENERAL OBSERVATIONS.

Duration of trial, hours,	10
Average steam pressure, pounds,	69,352
Average temperature of feed water to heater, Fahr.	66.5
Average temperature of feed water to boiler, Fahr. 152.73 =	153.339
Elevation of temperature by heater	86.839
Gain by heater, per cent	7.594
Average temperature of air in boiler room, Fahr.	80.727
Average temperature of waste gases in flue	494.024
Average barometer, inches,	29.881

CALORIMETER.

Average water heated, pounds,	200
Average steam condensed " "	10,118
Average initial temperature, F., 67.446 =	67.4626
Average final temperature, F., 119.865 =	120.1065
Average heat units per lb. of steam	1,160.706
Thermal units per pound of steam at observed pressure	1,210.07
Difference	49.37
Latent heat at observed pressure	891.88
Percentage of water entrained in the steam	5.535

TOTALS.

Total water to boilers, pounds,	136,215.0
Total water entrained in the steam, "	7,539.5
Total steam furnished, pounds,	128,675.5
Steam per hour, pounds,	12,867.5
Total coal burned, pounds,	19,073
Total ash and clinker, and unburnt coal weighed back, pounds,	2,813
Percentage of combustible	85.4
Coal per hour, pounds,	1,907.3

ECONOMY.

Steam per pound of coal from temperature of feed water, pounds,	6.746
Steam per pound of coal from and at 212, Fahr., pounds,	7.382
Steam per pound of combustible from and at 212 Fahr., pounds,	8.644

Steam per square foot of heating surface per hour.....pounds, 6.827
Coal per square foot of grate surface, per hour.....pounds, 10.837

COAL FOR BANKING AND STARTING FIRES.

CYLINDER BOILERS, MAIN HOUSE.

Wednesday morning, August 29th, pounds, 4,627.*

The low rate of evaporation by the Main tubular boilers, and the very low temperature of waste gases in the smoke extension, seem to indicate that an improved economy may be had by causing the plant to do more work.

The rate of work for trial of Aug. 27 was in round numbers 12,500 pounds of steam per hour if the evaporation for the boilers as a whole, was increased to 14,500 pounds per hour. The writer believes the economy would be sensibly enhanced.

The difference in work is about equivalent to that of three of the plain cylinder boilers.

The economy of the plain cylinder boilers is good for the class. The writer's experience, however, with this type of boiler, is very limited, their use in the West being confined to blast and puddling furnaces, where the waste gases from the furnaces are conducted under the boilers in transit to the chimney. In these cases the steam made is clear gain, for otherwise the waste furnace gases would pass into the chimney at a high temperature, and a large percentage of the thermal power of the fuel be lost. The writer knows, however, from English data upon the plain cylinder boiler, that high economy is not had excepting with shells of large diameter, and then the economy is always inferior to well-designed tubular boilers, owing to the naturally high temperature of waste gases passing into the flue, representing a large percentage of loss of heat, a portion of which is bound to be absorbed in the tubes of a tubular boiler, and made to assist in the production of steam.

Of the total heat of combustion with the plain cylinder boilers of the Rubber Company, from 20 to 25 per cent. is carried off by the waste gases into the stack, whilst 12 to 15 per cent. is known to be sufficient to produce good chimney draft.

The writer respectfully suggests that no possible change in the plain cylinder boilers could improve their economy up to a fair standard.

The shells (30″) are too small in diameter to hope for any excellence, even if the boilers were divided into two lengths of 15′ each, and filled with tubes, the only way in which the economy can be increased.

The writer's experience leads to the opinion that long boilers of small diameter are not as safe against rupture as short boilers of large diameter; the latter are more compact, stronger for transverse strains, less liable to injury from expansion and contraction, and with equal factors of safety more liable for continuous use.

PUMP-HOUSE BOILERS.

These boilers, of which there are two, set in independent furnaces, are of same general dimensions and plan as the boilers of North-house, but with fewer tubes. Each boiler has its own feed and smoke connection, check and stop valves, and steam and water gauges.

In the smoke connection which passes aft over the top of setting, a fuel economizer is placed, through which the feedwater is pumped in transit to the boilers.

The feed pump is now driven by the Worthington pumping engine, but, as demonstrated during the trial, is entirely inadequate to the requirements of boilers, and should be replaced by an independent boiler feeder set in the boiler-room, capable of furnishing a delivery against boiler pressure of 300 gallons per hour. The present feed pump is not equal to the requirements of one boiler by nearly 15 per cent.

In the following table are given the dimensions of boilers, partly from contractors drawing and partly from personal measurements.

DIMENSIONS OF BOILERS, PUMP HOUSE.

Style		Tubular.
Number		2
Diameter of shells	inches	48
Length of shells	feet	14
Tubes		49–3″
Grate		4′×4′ 6″
Heating surface each boiler	sq. ft.	626.742
Grate surface, each boiler	"	18.000
Tube vent	"	2.021
Ratio heating to grate surface		34.819

* The coal 4,627 pounds to start fires Wednesday morning, Aug. 29th, under plain cylinder boilers, is a fair quantity and represents a fire four inches thick upon whole grate.

Ratio grate surface to tube vent	8.906
Total heating surface, 2 boilers, sq. ft.	1,253.484
Total grate surface, 2 boilers... "	36
Chimney height..... feet	73.5
Chimney cross section .....sq. ft.	5.444
Ratio total grate surface to cross section of chimney.....	6.613
Space over bridge wall.....inches	12
Space over grate..... "	23

Builder ...Whittier Machine Co., Boston.

Two trials were made with these boilers, the second of which alone is reported.

The steam pressure and management of the coal for first trial, not fairly representing average performance.

The second trial should have been of greater duration, but the inability of the feed pump (furnished with the Worthington engine), to supply the boiler, limited the trial to eight hours during which time all the delivery of the feed pump was evaporated, besides boiling down the level of water in the boiler nearly 1500 pounds.

The boiler exhibits a good economy, size considered, and the size is ample for the work required.

PERFORMANCE OF PUMP-HOUSE BOILER.

Date of trial.....	Sept. 3
Boilers used	1
Heating surface.....sq. ft.	626.742
Grate surface..... "	18.

GENERAL OBSERVATIONS.

Duration of trial.....	8 hours.
Average steam pressure.....pounds	67.422
Average temperature of feed water to boiler, Fahr.....	69.333
Average temperature of feed water to boiler.....157.906=158.595	
Elevation of temperature by heater.	89.243
Gain by heater..... per cent.	7.824
Average temperature of air in boiler room, Fahr.....	80.531
Average temperature of waste gases, smoke connection.....	292.937
Average barometer..... ..inches	29.935

CALORIMETER.

Average water heated.....pounds	200.
Average steam condensed.. "	10.423
Average initial temperature, Fahr..72.5=72.525	
Average final temperature, Fr.120.797=121.046	
Average heat units per lb. of steam.	1,052.082
Thermal units per pound of steam at observed pressure	1,209.56
Difference.....	157.478
Latent heat at observed pressure...	893.09
Per centage of water entrained in the steam.....	17.63

TOTALS.

Water pumped into boiler...pounds	8,817.186
Water level reduced .6.25"=pounds	1,484.966
Total water to boiler..... "	10,302.152
Total water entrained in steam "	1,816.269
Total steam furnished..... "	8,485.883
Steam per hour..... "	1,060.735
Total coal burned..... "	1,000.000
Total ash and clinker and unburnt coal weighed back.....pounds	38.00
Per centage of combustible.....	96.2
Coal per hour.....pounds	125.0

ECONOMY.

Steam per pound of coal from temperature of feed water ...pounds	8.486
Steam per pound of coal from and at 212 Fahr.....pounds	9.233
Steam per pound of combustible from and at 212 Fahr.....pounds	9.5977
Steam per square foot of heating surface per hour.....pounds	1.692
Coal per square foot of grate surface per hour.....pounds	6.944

The Storm water tank collecting the water from the roof of pump house was measured for delivery of feed to the boiler and found to be of following dimensions:

Diameter of tank.....feet	10
Height of tank..... ..... "	9
Capacity.....gallons	5,287.313
Capacity at 60 F... .....pounds	44,043.31
Weight per foot of depth.... "	4,893.66

In the following table are given the economic and capacity data from the several trials of boilers:

STEAM PER POUND OF COAL FROM TEMPERATURE OF FEED.

		Pounds.
First trial, North boilers (tubular) temperature feed.....161.547		7.6648
Second trial, North boilers (tubular) temperature feed.....	153.87	8.414
Second trial, Main boilers (tubular) temperature feed.....	117.59	10.091
First trial, Main boilers (cylinder) temperature feed.....	152.73	6.746
Second trial, pump house (tubular) temperature feed.....157.906		8.486

STEAM PER POUND OF COAL FROM AND AT 212 FAHR.

	Pounds.
First trial, North boilers (tubular)	8.349
Second trial, North boilers (tubular)....	9.2554
2d trial, Main boilers(tubular) (Main)	(11.5209
1st trial, " (cylinder) (House)	(7.382
Second trial, Pump house (tubular)....	9,233

STEAM PER POUND OF COMBUSTIBLE FROM AND AT 212 FAHR.

	Pounds.
First trial, North boilers (tubular).....	9.123
Second trial, North boilers (tubular) ...10.5259	
2d trial, Main boilers (tubular) (Main)	13.2934
1st trial, " (cylinder) (House)	8.644
2d trial Pump house boilers (tubular) ..	9.597

COAL BURNED PER SQUARE FOOT OF GRATE PER HOUR.

	Pounds.
First trial, North boilers (tubular).....	10.84
Second trial, North boilers (tubular)....	5.0187
Second trial, Main boilers (tubular)....	7.424
First trial, Main boilers (cylinder).....	10.837
2d trial Pump house boilers (tubular)..	6.944

STEAM PER SQUARE FOOT OF HEATING SURFACE PER HOUR.

	Pounds.
First trial, North boilers (tubular).....	1.778
Second trial, North boilers (tubular)....	0.9036
Second trial, Main boilers (tubular)....	1.575
First trial, Main boilers (cylinder).....	6.827
2d trial, Pump-house boilers (tubular)..	1.692

In the following table are recapitulated the rates per hour, at which the coal was fired in the several trials:

				Pounds.
1st trial, North boilers,	all day,	1	fireman	693.75
" "	day run,	1	"	675.
" "	night "	1	"	712.5
2d trial, "	all day,	1	"	321.2
" "	day run,	1	"	286.516
" "	night "	1	"	366.
2d trial, Main tubular boilers,		2	"	1,236.1
1st trial, Main cylinder boilers,		2	"	1,907.3
2d trial, Pump house boilers,		1	"	125.

Omitting any changes calculated to diminish the consumption of steam for power, which the writer will discuss under the head of engine peformance, and assuming a production of steam in the north house midway between the work of first and second trials, and the production of steam in the main house the same as for second trial, of tubular boilers and first trial, of cylinder boilers, then the total daily steam from these plants, becomes—

	Pounds.
North house, August 20–21, 24 hours...	96,240
Main house, tubular, Aug. 27 (10 hrs.)	125,000
" cylinder, " 29 (10 hrs.)	128,600
Per diem, pounds steam.....	349,840

representing upon basis of trials, a consumption of coal per diem exclusive of that required to bank and start fires, of—

12,179.5 lbs., 24 hours, North house (tubular).
12,361.0 lbs., 10 hours, Main house (tubular).
19,073.0 lbs., 10 hours, Main house (cylinder).

43,613.5 lbs., per diem, pounds coal.

Add to this the coal required to start fires Monday morning north house, 2,500 pounds, equivalent to 420 pounds per day, the coal to bank and start fires night and morning daily. Main house, of 4,246 pounds (Aug. 30th), for tubular boilers, and 4,627 pounds (Aug. 29th), for plain cylinder boilers, then total daily consumption as per logs of trials, becomes 52,906.5 pounds, or 26.5 tons in round numbers, for North house and Main house under assumed conditions of load and present conditions of performance for North house, and present conditions of load and performance for Main house, representing an annual cost of $26.5 \times \$5.50 \times 300 = \$43{,}725.00$.

Assuming that the boilers of North house are replaced with three six foot tubulars (same dimensions as of Main house), and that the sixteen cylinder boilers of Main house are replaced with six six-foot tubulars (same dimensions as present tubular boilers), then the consumption of coal per diem for same work as before with same temperature of feed as obtained by trial, will be—

For proposed three (3) new tubular boilers for North house temperature of feed.

$$\frac{161.547 + 153.87}{2} = 157.708 = 158.4 \text{ true heat,}$$

then

$$\frac{(1210.33 - 107.746) \times 10.091}{1215.49 - 158.4} = 10.425 \text{ lbs.}$$

of steam per pound of coal upon evaporation of present six-foot tubular boilers, and $\frac{96{,}240}{10.525} = 9{,}144$ pounds of coal per diem of 24 hours, exclusive of coal to start fires Monday morning, which should average 2,400 pounds or 400 pounds per day, distributed through the week; and total daily consumption will be 9,544 pounds.

For present six (6) Main tubular boilers as per trial (Aug. 27th) 12,361 pounds for the day of 10 hours, and 4,246 pounds for banking fires and steaming up in the morning, or a total of 16,607 pounds per diem of 24 hours.

For proposed six (6) new tubular boilers, to do the work now accomplished by the sixteen (16) plain cylinder boilers in Main house.

Temperature of feed to boilers 152.73 = 153.34 true heat then,

$$\frac{(1210.33 - 107.746) \times 10.091}{1210.07 - 153.34} = 10.529 \text{ lbs. of}$$

steam per pound of coal upon evaporation of present six-foot tubular boilers in Main house, and $\frac{128{,}600}{10.529} = 12{,}214$ lbs. per day of 10 hours, and 4,246 pounds of coal for banking fires and steaming up in the morning, or a total consumption of 16,460 pounds per diem of 24 hours.

And total consumption of coal per diem 24 hours.

North boilers (3) tubulars,	9,544, steam	96,240
Main boilers (6) tubulars (present)	16,607, steam	125,000
Main boilers (6) tubulars (new)	16,460, steam	128,600
	42,611	349,840

or a total consumption per annum of $\frac{42,611}{2000} = 21,305 \times 300 = 6,391.5$ tons at $5.50 per ton = $35,153.25 or a saving of $8,571.85 based on present work for Main house. and an increase over present work for North house of fifty per cent.

But it will appear upon investigation of the motive power, that changes can be made which will diminish the consumption of steam from Main house very materially, and increase the saving of fuel over above estimate by several thousand dollars per annum.

Motive Power.

The motive power of the new works is furnished by a Harris Corliss condensing engine, fitted with a pair of Gannon surface condensers, the condensation and air from which is removed by an independent air pump of the Deane pattern.

The power is taken from the pulley fly-wheel by two four-foot double leather belts, (running upwards of a mile a minute); to two main line shafts, from which it is distributed to the different parts of new works, principally by belts and pulleys, with two line shafts lying at right angles to main lines which are driven by bevel gearing.

The motive power of the old works is furnished by a pair of Harris Corliss non-condensing engines, running coupled, and connected by a spur gearing to the main line shaft.

The principal machinery driven by the condensing coupled engines is

4	Calendering machines
6	Washing "
8	Warming "
20	Grinding "

The principal machinery driven by the non-condensing coupled engines is

8	Calendering machines
8	Warming "
20	Grinding "

In the following table are given the dimensions of the condensing engine:

Dimensions Harris Corliss Engine.

Style	Condensing.
Diameter of cylinder, inches	36
Stroke of piston, "	72
Diameter of piston rod, "	5.25
Steam ports (each), "	1.5×36
Exhaust ports (each), "	2.875×36
Area, front side of piston, sq. inches	996.251
Area, back side of piston, "	1,017.9
Nominal revolutions per minute	50.
Nominal piston speed per minute, feet	600.
Actual piston speed, economy trial, Aug. 28, feet	601.8635
Factor of H. P., front side piston, nominal speed	9.057
Factor of H. P., back side piston, nominal speed	9.253
Piston stroke to release in parts of stroke	0.9888
Piston stroke from ex.'closure in parts of stroke	0.0902
Clearance in parts of stroke	0.025

Data from Economy Trial.

Piston displacement per hour to release, cu. feet	249,901.45
Piston displacement per hour to ex.' closure, cu. feet	22,796.44
Clearance volume, per hour. "	5,054.64
Pulley fly-wheel diameter, feet	27.
Pulley fly-wheel face, inches	96.
Pulley fly-wheel weight, tons	39.

Surface Condenser, 36″×72″ Engine.

DOUBLE DIMENSIONS.

25 rows of brass tubes, 8 tubes in each row.

Tubes 200 — 0.875″ outside diameter, 6 feet 1.5″ long.

Returns 25, radius of bend, 1.875″, diameter, 1.25 inches.
Returns 25, radius of bend, 4.25″, diameter, 1.00 inches.
Returns 25, radius of bend, 6.875″, diameter, 1.00 inches.
Returns 25, radius of bend, 8.75″, diameter, 1.00 inches.

Cooling surface in tubes, sq. ft.	280.525
Cooling surface, 100 returns, "	38.062
Total cooling surface, 1 condenser, "	318.587
Total cooling surface, 2 " "	637.174

Maker....Gannon, Jersey City, N. J.

Two trials for economy were made of the condensing engine: the first trial was unreliable by leakage of hose used to convey the discharge of the air pump to the weighing tank, and second trial is alone reported.

In the following table are given the principal data from second trial:

Harris Corliss, 36×72″, Condensing Engine.

Economy Trial, Aug. 28th.

Duration of trial, hours, 10

AVERAGES.

Average steam pressure in pipe, pounds	70.137
Average barometer, inches	30.194
Average barometer, pounds	14.822

Average vacuum condenser.....inches	20.473
Average vacuum, condenser....pounds	10.050
Average temperature of injection, Fahr.	72.225
Average temperature of overflow, "	97.675
Average temperature of condensation"	104.037

ENGINE COUNTER.

Counter at 7.02 A.M.....	356.
Counter at 12.00 M.....15,285.	
	14.929
Counter at 1.00 P.M 15,626	
Counter at 6.00 P.M.....30,688	
	15,062
Revolutions, 9 hours 58 minutes.....	29.991
Revolutions per minute.....	50.155
Piston speed.....	601.8635

FROM THE DIAGRAMS.

Average initial pressure.....pounds	68.795
Average terminal pressure absolute, "	8.933
Average counter pressure at mid-stroke, absolute .....pounds	5.383
Average vacuum realized..... "	9.439
Av. mean effective pressure {front "	21.069
{back "	21.699

LOAD.

Average indicated horse power 392.862	

RATIO OF EXPANSION.

Apparent cut-off in parts of stroke....	0.084
Actual cut-off in parts of stroke.....	0.104
Theoretical cut-off.....	0.10895
Expansion by volumes	9.718
Expansion by pressures.....	9.36

CALORIMETER.

Average water heated..... ..pounds	200.
" steam condensed.... "	10.162
" initial tem'ture, Fahr.....79.45=79.489	
" final " " ..130.150=130.481	
" thermal units found in steam	1,134.020
Thermal units in steam at observed pressure.....	1,210.33
Difference.....	76 309
Latent heat of steam at observed pressure.....	891.29
Per-cent. of water entrained in steam.	8.561

ECONOMY.

Total water weighed from condenser.....pounds	82.088
Actual saturated steam to engine "	75,103.426
Net steam to engine per hour.pounds	7,510.342
Steam per ind. H.P. per hour "	19.095
Coal per ind. H.P. per hour, based upon main tubular boilers	1.892
Per-centage of steam accounted for by indicator.....	74.048
Steam per indicated H. P. per hour by diagrams	14.139

SURFACE CONDENSER.

Steam condensed per sq. foot of cooling surface per hour.....pounds	11,787

The economy of the engine is excellent, but is scarcely up to the standard of Harris Corliss' engines. With an increase of load to about 600 horse power, the writer is of the opinion that the consumption of steam per horse power will be reduced about fourteen per cent.

With 80 pounds pressure in the pipe, and a mean initial pressure of 79 pounds, the mean effective pressure with a cut off at 12 per cent. of the piston's stroke, and vacuum of 26 inches, would be about 33 pounds, equivalent to a load of 600 horse power in round numbers. The terminal pressure under these conditions will be 13 pounds absolute, and counter pressure 3.5 pounds absolute, corresponding to a consumption of stean per hour by the diagrams of 8,367 pounds, or 13.995 pounds per indicated horse power; under the proposed conditions, I expect the diagrams to account for not less than 85 per cent. of net steam delivered to engine, whence actual consumption of steam per horse power per hour would be 16.416 pounds, and gain over present economy would be $1 - \frac{16.416}{19} = \frac{1365}{10000}$ or nearly *fourteen* per cent.

The estimated economy upon a load of 600 horse power is within personal precedent from Harris Corliss' condensing engines, and can be obtained, and possibly improved, by the Rubber Co's. engine.

The writer's belief is, that with a load of 600 horse power, pressure of 80 pounds in pipe at engine, and a vacuum of 26 inches in condenser, the economy will excel the best he has ever obtained from condensing single cylinder engines, and he has placed the gain at fourteen per cent. as a maximum to be expected.

The expenditure of condensing water for the $36'' \times 72''$ engine has been roughly estimated in the following manner:

Thermal units taken up per pound of condensing water $97.675 - 72.225 = 25.45$ thermal units per pound of steam, difference between observed total temperature of steam as it entered engine and as it left the condenser $1{,}134.02 - 104.037 = 1{,}029.983$, of which quantity the heat converted into work, and that lost by radiation and conduction during expansion in the cylinder, represents about ten per cent. (all heat converted into work or lost by conduction and radiation prior to cut off being supplied direct from boilers), leaving 926.98 thermal units to be taken up by condensing water, corre-

sponding to 36.42 pounds per pound of steam condensed; the weight of steam condensed per hour was 8,208.8 pounds, and weight of condensing water due this quantity of steam was 299,964 pounds, or 36,010 gallons, or about 68 per cent. of capacity of Worthington pump at wharf based upon delivery during the duty trial (53,790 gallons per hour), 36,000 gallons of sea water pumped 100 feet high equals 3.6 million gallons one foot high, and will cost for fuel alone, not including coal to start fires, $0.216 or $21\frac{6}{10}$ cents for 393 horse power, or at rate of $2.16 per day of ten hours, or 1.82 horse power per *one* cent of cost. The coal for ten hours per horse power is 0.25 bushels, and costs $5\frac{1}{2}$ cents or a total cost per horse power per diem (10 hours) of 6 cents in round numbers for fuel.*

The writer is of the opinion that few establishments, in or out of the United States, can exhibit a similar economy for motive power.

In the following table are given the dimensions of the non-condensing coupled engines.

HARRIS CORLISS' NON-CONDENSING ENGINES.

Two coupled cranks set on one shaft at quarters.

RIGHT ENGINE.

Diam. of cylinder.....inches,	28
Stroke of piston..... "	48
Diam. of piston rod..... "	4.125
Area front side of piston.....sq. in ,	602.386
Area back side of piston..... "	615.75
Nominal revolutions per minute.....	70.
Nominal piston speed per minute..ft.,	560.
Actual piston speed economy trial Aug. 30th.....ft.,	555.344
Factor horse power front side piston nominal speed	5.111
Factor horse power back side piston nominal speed.....	5.224
Piston stroke to release in parts of stroke.....	0.9906
Piston stroke from exclosure in parts of stroke.....	0 0489
Clearance in parts of stroke (estimated).....	0.025

DATA FROM ECONOMY TRIAL.

Piston displacement per hour to release.....cu. ft.,	137,317.49
Piston displacement per hour to exclosure.....cu. ft.,	6,778.54
Clearance volume per hour.. "	3,465.51

*Coal for steam per H. P. per hour..1.90 pds.,	$0.0055
Coal for Worthington pump at wharf to supply condensing water per H. P. per hour, ...0.2 pounds,	0.00055
Total coal 21 pounds per 10 hours.....	0.0605
or say, in round numbers six cents.....	6

LEFT ENGINE.

Diam. of cylinder.....inches,	26.
Stroke of piston..... "	48.
Diam. of piston rod..... "	3.875
Area front side of piston...sq. inches	519.137
Area back side of piston .. "	530.93
Nominal revolutions per minute.....	70.
Nominal piston speed " " ...ft.,	560.
Actual piston speed economy trial Aug. 30th.....ft.,	555.344
Factor horse power front side piston nominal speed.....	4.405
Factor horse power back side piston nominal speed.....	4.505
Piston stroke to release in parts of stroke.....	0.9926
Piston stroke from exclosure in parts of stroke.....	0.0448
Clearance in parts of stroke (estimated).....	0.025

DATA FOR ECONOMY TRIAL.

Piston displacement per hour to release.....cu. ft,	120,588.04
Piston displacement per hour to exclosure.....cu. ft.,	5,442.62
Clearance volume per hour.. "	3,037.17
Fly wheel diam. .....ft.,	20.
" " weight.....tons,	18.5

One trial for economy of coupled engines was made Aug 30th, under ordinary conditions of work in the old mill, with the following results:

ECONOMY TRIAL COUPLED ENGINES.

Date of trial.....	August 30th.
Duration of trial.....10 hrs. 45 min.	

PRESSURES.

Average pressure in pipe.....pounds	68.488
Barometer estimated.....inches,	29.9
" " .....pounds,	14.678

ENGINE COUNTER.

Counter at 7.01: A. M.....17,917	
Counter at 6: P. M.....62,622	
Revolutions for 10 hours 44 minutes..	44,705
Revolutions per minute.....	69.418
Piston speed.....ft.,	555.344

FROM THE DIAGRAMS 28"×48" ENGINE.

Average initial pressure.....pounds,	60.415
Av. terminal pressure absolute "	13.094
Av. counter pressure above atm. "	0.914
Mean effective pressure front side of piston.....pounds,	14.915
Mean effective pressure back side of piston ..... pounds,	13.954
Indicated horse power.....	147.886

FROM THE DIAGRAMS 26"×48" ENGINE.

Average initial pressure.....pounds,	60.953
Av. terminal pressure absolute "	15.794
Av, counter pressure above atmosphere..... pounds,	1.787
Mean effective pressure front side of piston ..... pounds,	23.484
Mean effective pressure back side of piston.....pounds,	22.026
Indicated horse power.....	200.980
Total load average all day H. P.....	348.875

RATIO OF EXPANSION 28″×48″ ENGINE.

Apparent cut-off in parts of stroke.....	0.1299
Actual " " " "	0.155
Theoretical " " " "	0.1743
Expansion by volumes.....	6.613
" " pressures.....	5.735

RATIO OF EXPANSION 26″×48″ ENGINE.

Apparent cut off in parts of stroke....	0.235
Actual cut off in parts of stroke.....	0.26
Theoretical cut off in parts of stroke....	0.209
Expansion by volumes	3.942
Expansion by pressures.....	4.788

CALORIMETER.

Av. water heated.....pounds,	200.
Av. steam condensed.....pounds,	10.159
Av. initial temperature, Fahr...77.386=	77.421
Av. final temperature, Fahr..129.75=	130 079
Av. thermal units found in steam,....1166.759	
Thermal units in saturated steam at observed pressure	1209.82
Difference thermal units.....	43.061
Latent heat of steam at observed pressure.....	892.49
Percentage of water entrained in the steam	4.824

TOTALS.

Total water weighed to boilers..lbs.	125,745.
Total water and steam to calorimeter..... ..pounds,	234.5
Total water and steam to engine lbs.	125,510.5
Total saturated steam to engine.lbs.	119,455.9
Estimated steam to machine-shop engine.....pounds	8,806.0
Net steam to coupled engines "	110,649.9

ECONOMY.

Steam per hour..... pounds,	10,293.014
Steam per hour per indicated H. P .....pounds	29.503
Coal per horse power per hour upon performance of tubular boilers, Main House.....	2.924

STEAM ACCOUNTED FOR BY DIAGRAM.

By 28″×48″ engine per hour..pounds	4,377.6
By 26″×48″ engine per hour.. "	4,712.5
By both engines ..... "	9,090.1
Percentage accounted for	88.313
Steam per indicated H. P. per hour by diagrams.... .....pounds	26.054

Of above load, 46.285 horse power is due to friction of engine and load, and 302.59 horse power represents average load of machinery, including friction of line shafting and gearing, which would be the net average load if the old works were driven by the condensing engine.

The aggregate average load in old and new works, now driven by condensing (36″x72″) engine, and non-condensing coupled engines, is 741.737 horse power, and the aggregate maximum load in the old and new mills from accompanying tables of power per diem, is 949.551 horse power.

In providing for capacity of engine the maximum possible loads should be considered, and in prospecting for economy, the average loads should be considered.

Suppose the total load of old and new mills is divided between the 36″x72″ condensing engine, and the 28″x48″ engine (made condensing), and that the loads are proportioned for best mean effect for the two engines.

Calling the whole load 100, then of this there should be carried by the 36″x 72″ engine 64 per cent., and by the 28″x 48″ engine 36 per cent.; or if the 36″x 72″ and 26″x48″ were run together, which (with the two engines in same condition), is to be preferred for economy; then 68 per cent. of the load to the 36″x72″ engine, and 32 per cent. to the 26″x48″ engine, both engines condensing and producing as nearly as possible similar diagrams.

The writer's recollection now is that the 28″x48″ engine is in much the better condition of the coupled engine, and would probably be a better engine to carry the proportional part of total load.

Of the aggregate average indicated power of condensing and coupled engines, 32.042 horse power is the friction of the 36″x72″ engines running without load at mean speed, 18.086 horse power is the friction of 28″x48″ engine running without load at mean speed, and 15.592 horse power is the friction of 26″x48″ engine under similar conditions.

If the 26″x48″ engine is stopped, then of the aggregate average load (7.42 horse power in round numbers) 15.6 horse power of load would be removed, leaving 726.4 horse power to be furnished jointly by the 36″x72″ engine, and 28″x 48″ engine, of this the former engine should carry 465 horse power, as a mean load, and 600 horse power as a maximum load, and the 28″x48″ engine should carry 261.4 horse power as a mean load, and 335 horse power as a maximum load (while working condensing). Under these conditions both engines would be so moderately loaded as to warrant excellent wear through many years of continuous service.

The consumption of steam for power alone under proposed arrangement, will be 12,348.8 pounds per hour, or 123.481 pounds per diem of ten hours, correspond-

ing to a consumption of coal, upon basis of 72″ tubular boilers in main house of 12,237.4 pounds, or 6.1187 tons.

The consumption of steam from main house at time of trials, August 27th to September 4th, was:

From 6 tubular boilers, 124,729.66 pounds.

From 16 plain cylinder boilers, 128,-657.50 pounds.

Total steam for 10 hours, 253,405.16 pounds.

Representing a coal consumption for same time of 12,361 pounds for tubular boilers, and 19,073 pounds for plain cylinder boilers, or a total per diem of 31,434 pounds, or 15.717 tons, exclusive of coal to bank and start fires.

Of above quantity of steam as at present working, the 36″x72″ condensing engine consumed (August 28th) 75,103,-426 pounds per day (10 hours), the coupled engines, as run August 30th, consumed 110,650 pounds per day, the machine shop engine consumed 8,806 pounds per day, and the steam pumps and various heating and curing apparatus taking steam from main boilers, consumed the remainder, or 58,845.73 pounds per day; of this the consumption by pumps alone will not exceed 10,000 pounds per day, leaving consumption of steam by heating, devulcanizing and curing apparatus, as at date of trial, of 48,850 pounds in round numbers.

The hourly quantities which is the better method of stating steam consumption, is:

For 36″ × 72″ engine.	392.86 H. P.	7,510.34 lbs.
For coupled engines.	348.87 H. P.	11,065.00 "
For machine-shop engine.....	31.45 H.P.....	880.60 "
For steam pumps { (2 boiler feeders) (1 fire pump....)		1,000.00 "
For heating rolls, devulcanizing and curing apparatus.....		4,884.573 "

The above, as working at dates of trial, represented an annual (300 days) consumption of fuel for all purposes (banking and starting fires, and running), of 6,046.2 tons, or an expenditure of $33,254.

Under proposed arrangement with 28″x48″ engine, condensing, the expenditure of steam per hour will be:

For 36″ × 72″ engine	465 H P...	7,905.0 lbs.
For 28″ × 48″ engine	261.4 H.P....	4,443.8 "
For 10″ × 24″ engine	31.45 H.P....	880.6 "
For 3 steam pumps { reduced duty (of boiler feeders)		800.0 "
For heating, devulcanizing and curing.....		4,884.5 "

or a total consumption of steam per day of 10 hours, of 189,285.5 pounds, equivalent to an expenditure of 18,758 pounds, or 9.379 tons of coal, and an annual (300 days) consumption of 2,813.7 tons at a cost of $15,475.35 running time, to which add coal for banking and starting fires, as follows:

For present six tubular boilers per day...	4,246 lbs.
For proposed 3 additional tubular boilers to take the place of present 16 plain cylinder boilers.....	2,123.0 "
Total.....	6,369.0 "

or 3.184 tons per day, or 955.2 tons per annum, costing $5,253.60, making a total cost for fuel under proposed arrangement of $20,728.95 in main boiler house.

To recapitulate the proposed changes, contemplate:

First—The removal of the 16 plain cylinder boilers, and substitution of 3 tubular boilers of same dimensions as present tubular boilers, *videlicit*, 72″ diameter of shell 15′ long, with 100-3″ tubes to be set, and otherwise arranged as present (6) tubular boilers.

Second—The addition of a condenser to the 28″x48″ Harris Corliss non-condensing engine.

Third—The division of the whole motive power between the 36″x72″ condensing engine, and the 28″x48″ condensing engine, in the proportion of 64 per cent. to the former, and 36 per cent. to the latter, making a difference in cost of power between arrangement as at date of trial, and proposed arrangement of $12,526.05 per annum, from which we must deduct the extra cost of fuel at pump house to supply condensing water to condensers of 36″x72″ engine, and 28″x48″ engine, which upon basis of estimate for 36″x72″ engine with present load (August 28th) will be $550, leaving a net difference of $11,976.05. By substituting for the present 5-48 inch tubular boiler in the North house, 3.72 inch tubular boilers of same size as the tubular boilers in the Main house, and estimating the average requirements of said boilers to be midway between the ordinary work as per trial of August 21st, and the maximum consumption as per trial of August 20th and 21st, then

the difference in cost of steam in favor of the 3-72-inch boilers will be $2,524.50, and a total possible improvement (in sight) of economy of $14,500.55.

The suggested improvement in boiler economy is based upon precedent in the Rubber Company's own works, and the suggested improvements in engine economy is based upon personal experience with Harris Corliss and other cut-off steam engines.

The testing of the 10″x24″ machine-shop engine was incidental to the test of coupled engines, and furnishes valuable information only in the power developed, and probable cost of operating the machinery of machine-shop and box-factory.

MACHINE-SHOP ENGINE.

DIMENSIONS.

Diam. cylinder	inches	10
Stroke of piston	"	24
Diam. of piston rod	"	1.9375
Diam. of fly wheel	feet	7.5
Width of fly-wheel face	inches	16.
Weight of fly wheel	pounds	3880.
Clearance estimated	per cent.	3.
Area front side piston	sq. inches	75.592
Area back side piston	" "	78.540
Estimated revolutions per minute		100.
H. P. front side piston		.458
H. P. back side piston		.476

The mean speed during trial was 100.-749 revolutions per minute, and mean effective pressure front end of cylinder, 28.057 pounds, and for back end of cylinder, 38.583 pounds, equivalent to a mean load of 31.45 horse power. The estimate of 28 pounds of steam net, per horse power per hour, is justified by the general condition of the engine and the load carried, and any error in estimating the economy of this engine is calculated to enhance rather than diminish the economy of coupled engines, which were tested simultaneously with this engine.

The power developed by the machine-shop engine is relatively so small, that an error of several pounds in steam consumption per horse power per hour, might subsist, with no practical effect upon the economy of coupled engines.

DISTRIBUTION OF POWER.

Subsequent to the trials for economy of engines, tests were made upon 36″x72″ condensing engine, and 28″x48″ non-condensing engine for distribution of power, with the following results:

DISTRIBUTION OF POWER 36″ × 72″ ENGINE.

NEW WORKS.	H. P.
A load, average as at 2 P.M. Aug. 31.	415.316
B load consisting of 4 calenders, engine, line shafting and empty rolls.	118.207
C load, consisting of 3 calenders, engine, line shafting and empty rolls.	103,510
D load, consisting of 2 calenders, engine, line shafting and empty rolls.	98.528
E load, consisting of 1 calender, engine, line shafting and empty rolls.	82.193
F load, consisting of engine, line shafting and (44) empty rolls	77.000
G load, consisting of 8 warmers, engine, line shafting and empty rolls.	234.84
H load, consisting of 30 grinders, engine, line shafting and empty rolls.	502.352
I load, consisting of 6 washers, engine, line shafting and empty rolls	114,959
J load, consisting of 10 grinders, engine, line shafting and empty rolls.	198.004
K load, consisting of 10 grinders, engine, line shafting and empty rolls.	259.096
L load, consisting of 10 grinders, engine, line shafting and empty rolls.	238.297

The friction of empty engine at mean speed the writer has estimated at 1.75 pounds per square inch of piston, or 32.042 H. P. Deducting this amount from any of above loads, gives the gross load on engine, which consists of the machinery driven and extra friction of engine due to load; as the machinery cannot be operated without developing this extra friction, the writer thinks it is proper to charge it to the machines as part of the power required to drive them; of course the actual power consumed at the machine is as much less than that shown as is represented by extra friction of engine and connectors (line shafting and gearing), due to load; but if the load of machine is removed this extra friction disappears, and as in any particular instance, this extra friction is due to the load of machine, the writer thinks best to charge it as necessary part of the power to drive machine.

With this explanation the preceding table shows:

First—That the frictional resistance at mean speed of line shafting and gearing, forming the connectors between engines and machinery, and of the rolls running empty in new works requires, 43.159 horse power.

Second—That the average load (all machinery in new mill), exclusive of engine friction and extra friction of engine due to load, is 367.943 horse power.

Third—That 4 calenders require, 41.207 horse power divided as follows:

	H. P.
1st calender, as per supt's mem.....	14.697
2d " " " "	4.982
3d " " " "	16.335
4th " " " "	5.193
Average per calender.....	10.302
Fourth, that 8 warmers require.....	157.84
Average per warmer.....	19.73
Fifth, that 30 grinders require.....	425.352
Average per grinder	14.178
Sixth, that 6 washers require.....	37.959
Average per washer.....	6.326
Seventh, that 10 grinders require.....	121.004
Average per grinder.....	12.100
Eighth, that 10 grinders require.....	182.096
Average per grinder.....	18.210
Ninth, that 10 grinders require.....	161.297
Average per grinder.....	16.130

The average for last three loads, or loads J, K and L is 15.48 horse power per grinder, while the average for same machines all on load A, shows 14.178 H. P. per grinder, the difference must have been due to different conditions of work in the two cases; that is, the grinders when run in gangs of ten were more carefully charged with gum, than when operated as a whole in load H.

DISTRIBUTION OF POWER 28" × 48" ENGINE.

OLD WORKS.

	H. P.
A load, average at 2:00 P.M., Sept. 4th.	401.541
B load, consisting of 8 calenders, engine gearing, line shafting and empty rolls.....	119.482
C load, consisting of 7 calenders, engine gearing, line shafting and empty rolls.....	112.475
D load, consisting of 6 calenders, engine gearing, line shafting, empty rolls	105.819
E load, consisting of 5 calenders, engine gearing, line shafting, empty rolls.....	102.188
F load, consisting of 4 calenders, engine gearing, line shafting, empty rolls.....	100.407
G load, consisting of 3 calenders, engine gearing, line shafting, empty rolls.....	87.761
H load, consisting of 2 calenders, engine gearing, line shafting, empty rolls.....	76.222
I load, consisting of 1 calender, engine gearing, line shafting, empty rolls.....	61.609
J load, consisting of 8 warmers, engine gearing, line shafting, empty rolls.	213.938
K load, consisting of 10 mixers, engine gearing, line shafting, empty rolls.	176.908
L load, consisting of 10 mixers, engine gearing, line shafting, empty rolls.	151.780
M load, consisting of 20 mixers, engine gearing, line shafting, empty rolls.	288.498
N load, consisting of 8 warmers and 20 mixers, engine gearing, line shafting, empty rolls.....	389.207
O load, consisting of engine gearing, line shafting, and (28) empty rolls	54.421

The order in which the calenders were tested for power, was:

1st. Machine taken off.	1st. Empress calender.
2d. " "	2d. " "
3d. " "	Sole "
4th. " "	1st. 3 roll sheet "
5th. " "	2d. " "
6th. " "	4 roll sheet "
7th. " "	4 roll cloth "
8th. " "	Friction cloth "

The preceding table shows:—

First—That the frictional resistance at mean speed of gearing and line shafting, forming the connectors between engine and machinery of old works and of the rolls running empty, requires, 34.883 horse power, as against 43.159 horse power, for same losses in new works, but the new works contain a greater number of rolls permanently connected with line shafting, and a greater length of line shafting. (The number of rolls always driven in the old works is 28, and omitting difference of line shafting in the two cases, the average frictional resistance of gearing line shafting and empty rolls, per roll, is 1.246 horse power and for new works with 44 rolls always driven is 0.9809 horse power.

The power is transmitted in the old works to the line shafting by spur gearing, and in the new works by belting and the demonstration in the preceding paragraph shows conclusively that the loss of effect between engine and machinery is least with the belting connectors.

The fact is well established by numerous experiments however in flour mill practice, that the loss of power by frictional resistance of gearing is much greater than with belting, and no gearing which can be avoided is used in the large mills of the West to-day.

	H. P.
Second, that the average load (all machinery in old mill on), exclusive of engine friction, and extra friction of engine due to load, is.....	333.234
Third, that 8 calenders require.....	65.060
divided as follows:	
1st Empress calender.....	7.007
2d " "	6.656
Sole "	3.631
1st 3 roll sheet calender.....	1.781*
2d 3 " " "	12.746
4 " " "	11.539

* It is to be presumed there is an error in the power for first 3 roll sheet calender; where it subsists the writer cannot tell, but it is due, in all probability, to changes in the load of the machines on, at time *E* and *F* loads were indicated.

4 roll cloth calender	14.613
Friction cloth calender	7.187
Fourth, that 8 warmers require	159.516
Average per warmer	19.940
Fifth, that 10 mixers require	122.486
Average per mixer	12.248
Sixth, that 10 mixers require	97.358
Average per mixer	9.736
Seventh, that 20 mixers require	234.076
Average per mixer	11.703
Eighth, that 8 warmers and 20 mixers require	334.785
Average per machine	11·957

In considering the tables of power obtained as these were, with work going into and out of the machines, and with possible variations of stock requiring more or less power, it should be understood that the results can only be approximative as at the particular time when diagrams were taken, and in some instances the power per machine must be above the average and in other instances below the average. Taken as a whole, however, it is believed the tables will prove of value.

Worthington Pumping Engine.

The engine is located in a neat pump house on the wharf, and delivers sea water into a large iron tank in the yard of the factory to supply the circulation to the engine condensers, water to urinals and hoppers, and if required, to furnish water for fire purposes.

The steam end of the engine is compound condensing fitted with a Lighthall surface condenser, taking circulating water from the force pump on one side of the condenser and returning the overflow to the force pipe on the opposite side of condenser, with a regulating valve in the force pipe intermediate of the injection and overflow pipes, aftera system patented by the writer Sept. 6th, 1883.

The water end consists of two double acting plunging pumps with central solid packing glands.

In the following table are given the principal dimensions of engines and pumps:

Dimensions of Pumping Engine.

Builder....H. R. Worthington, N. Y.

DUPLEX COMPOUND CONDENSING.

Diam. H.P. cylinders (2)	inches	12
Diam. L.P. cylinders (2)	"	18.5
Stroke H.P. pistons (2)	"	10
Stroke L.P. pistons (2)	"	10

DOUBLE ACTING PLUNGER PUMPS, CENTRAL GLAND.

Diam. of plungers (2)	inches	14
Nominal stroke of plungers (2)	"	10
Contact stroke of plungers (2)	"	10.375
Diam. pump rods, front (2)	"	1.875
Diam. pump rods, back (1) right	"	1.25
Diam. pump rods, back (1) left	"	1.375
Calculated discharge per quadruple stroke	U. S. gallons	26.3
Diam. suction pipe	inches	8
Diam. discharge pipe	"	10

Condenser Surface.

Builder....Wm. Lighthall, N. Y.

The preliminary test of the Worthington pumping engine was for capacity, or more properly speaking for relation of actual to calculated delivery of pumps. To this end the iron tank in the factory yard, which receives the discharge of pumps, was carefully measured for capacity, with the following results:

Internal diam. mean of 4 measurements	feet	20.08
Total vertical depth	12'	10.875
Net vertical depth to overflow pipe	12'	7.5
Total contents in cu. feet		3,998.06
Total contents in U. S. gallons		29,905.51
Contents per vertical foot	U.S. gals.	2368.75

The calculated delivery of pumps for nominal stroke, I have estimated in the following manner:

	Sq. in.
Area 14-inch plunger	153.94
Area of 1.875-inch plunger rod	2.7612
Area of 1.25-inch air pump rod, R engine	1.2272
Area of 1.375 feed pump rod, L engine	1.4849

Mean area of plunger right engine

$$\frac{(153.94-2.7612)+(153.94-1.2272)}{2}=151.9458$$

Mean area of plunger left engine

$$\frac{(153.94-2.7612)+(153.94-1.4849)}{2}=151.817$$

and mean area both plungers

$$\frac{151.9458+151.817}{2}=151.8814$$

And delivery of both pumps per revolution, or for four (4) single strokes of 10 inches each

$$\frac{151.8814\times 40}{231}=26.3 \text{ U. S. gallons.}$$

The tank in yard was drawn down until the head of water measured from a given datum in bottom of tank, $5\frac{3}{16}$ inches = 0.4323 foot when all outlets were carefully closed, and head pumped up to overflow, or 12.525 feet, showing an increase of head of 12.1927 feet, corresponding to an addition of 2,368.75 × 12.1927 = 28,881.48 gallons. Meanwhile the tank was filling the engine counter

was read at intervals of five minutes, and head in tank noted for corresponding intervals, the observers' watches at pump house and tank being first made to agree, and directly the water in tank broke over the edge of overflow pipe, the observer at tank noted the time to seconds, from which is obtained by log of engine counter 1103.6 quadruple strokes of engine, corresponding to interval of time during which head in tank was raised from 0.4323 foot to 12.1927 feet, or a plunger displacement based upon nominal stroke of $26.3 \times 1103.6 = 29{,}024.68$ gallons, showing a delivery of $\frac{28{,}881.48}{29{,}024.68} \times 100 = \frac{995}{1000}$ of plunger displacement, or a loss of action of .5 of 1 per cent. As a matter of fact the left pump actually worked to contact stroke, or 10.375 inches instead of 10 inches, while the right pump fairly worked to nominal stroke, whence the plunger displacement for above delivery was 29,662.26 gallons, and the loss of action really 2.59 per cent.

The loss of action is low, not so low as the writer has seen reported for some large Worthington engines, but likely as low as has ever been obtained when plunger displacement is based upon actual instead of nominal stroke. In this case the contact stroke is 3.75 per cent. greater than nominal stroke, this being the double clearance of steam cylinders, and in all those cases of losses of action under 2 per cent. for direct-acting engines, the writer is quite sure the nominal stroke has been exceeded by all or part of the clearance, and the calculated delivery has been based upon nominal stroke, which in such instances was short of true stroke, and leads to a false statement of pump efficiency.

The writer makes this statement not in criticism of the pump at the Rubber Company's works, but in criticism of the practice of builders of this class of pumping machinery, claiming an efficiency of water discharge which the writer is sure is incorrect, and calculated to mislead their patrons.

The trial for duty of Worthington pumping engine was made September 3rd, with the following results:

DUTY TRIAL WORTHINGTON PUMPING ENGINE.

Date of trial	Sept. 3
Duration of trial	hours 8

GENERAL OBSERVATIONS.

Average steam pressure	pounds 67.422
" temperature of injection	Fahr. 66.625
" " " overflow	" 91.25
" " " hotwell	" 107.437
" " " air	" 80.531
" vacuum	inches 22.219
" barometer	" 29.935

HEAD PUMPED AGAINST.

By water-pressure gauge on force pipe	pounds 36.182
By diff. tide in harbor and center water-pressure gauge	pounds 7.388
Allowance for extra frictional resistance	pounds 1.000
Total head	" 44.57
Total head	feet 102.868
Mean area of plungers	sq. inches 151.8814
Moment of water load	inch pounds 6769.354

ENGINE COUNTER.

Counter at 8:00 A. M.	1543.
Counter at 4:00 P. M.	17905.
Revolutions in 8 hours	16362.
Total plunger travel	feet 54540.
Foot-pounds work for 8 hours	369,200,567.05

TOTALS.

	Pounds.
Total water pumped into boiler	10,302.152
Total water and steam to calorimeter	243.2
Equivalent coal to calorimeter	23.607
Total coal to boiler	1000.
Net coal to engine	976.393
Duty of engine per 100 pounds of coal	ft.-pounds 37,812,701.14
Average temperature of feed water 157.906	158.595
Steam per pound of coal from feed	8.486

It will be observed from the table, that with an expenditure of 976.393 pounds of coal during running time, the engine and pumps made 16,362 quadruple strokes, or 16.76 strokes per pound of coal, equivalent to a delivery of 438 gallons of water into the tank at the works; and the corresponding delivery per ton of coal (running time), 877,200 gallons, or 90.236 million gallons 1 foot high at a cost of 6 cents per million gallons for fuel alone.

The probable daily consumption of coal in starting fires, will be 500 pounds, the amount of which should be kept separate from that used in running.

The cost of engineer, coal for starting fires, and interest on investment, being a constant quantity independent of water pumped per diem, it is obvious that as the demands upon the engine increase the economy of performance will increase

also, the writer does not mean that the duty of engines based upon coal burned during the running time will be enhanced, but that the duty based upon all expenses reduced to a coal basis will be increased.

By separating the weights of coal (daily) to start fires, from the weights of coal burned for running time, it can be determined with a slight calculation, how well the pumping house is managed in the following manner: If a division of the coal used for starting fires (for any length of time), by the number of days is in excess of 500 pounds per diem, and the number of quadruple strokes (revolutions) by counter for same time divided by the coal burned (running time), is less than 16.76 per pound, then the works are not well managed.

In other terms the standard for coal per day for starting fires should be 500 pounds, and the standard of quadruple strokes of pumps per pound of coal burned while pumping water, should be 16.76; which standards may be exceeded or improved by skillful management upon the part of the engineer.

The air pump furnished with the Worthington air pump engine is insufficient to properly void the condenser of air and condensation, and another should be supplied with ample capacity to keep in advance of the actual maximum requirements.

During the progress of the writer's discussion of the results, he has suggested several improvements which were used only to illustrate the particular portion of plant under consideration, and were not intended as improvements which should be inaugurated in fact, *e. g.*, the change in setting of present tubular boilers in North house, and substitution of six 72″ tubular boilers for present plain cylinder boilers in Main house.

The improvements which the writer submits to the Rubber Co's consideration, are:

The removal of the plain cylinder boilers entirely, and substitution of three (3) 72″ tubular boilers instead.

The addition of condenser to 28″×48″ engine, arranged to work with 26″×48″ engine if desired.

The stoppage of 26″×48″ engine entirely.

The division of load between 36″×72″ engine, and 28″×48 engine in the proportion of 64 per cent to the former, and 36 per cent to the latter.

The substitution of three (3) 72″ tubular boilers for the present 5—48″ tubular boilers in North house.

By making these changes in a proper manner the writer confidently believes the Rubber Co. will reduce the coal bills $15,000 a year, besides a reduction of labor in wheeling and handling coal.

There are, no doubt, other sources of loss about the works in the consumption of steam, which partly for lack of time, and partly because of the high normal temperatures during his visit, were not investigated.

It is advisable to put a permanent pyrometer in the flue leading to chimney of each battery of boilers, also to furnish convenient dormant platform scales in North house, Main house and Pump house. for the actual weighing of coal, and the coal should be reported so much for banking and starting fires and so much for running. The writer would also have an indicator permanently attached to cylinder of 36″×72″ and 28″×48″ engines, for periodical diagrams to be read for load and economy.

The 28″×48″ engine should be furnished with a permanent counter for daily report of revolutions, and daily reports of counters from 36″×72″ engine, and from Worthington Pumping engine, should be had to check the economy at the several points of coal consumption or steam use. The night men in Main boiler house, and each fireman in North house should be required to brush the boiler tubes each night and at end of each watch respectively.

The foregoing narrative which is an extract from the report to the Rubber Co., may be crude in form and diction, but is, nevertheless, valuable as showing how meritorious improvements may be made in the steam power plants of large establishments, where no losses are supposed to exist. The engines and boilers of the National Rubber Co. are, strictly speaking, first class, yet with precedents from its own works, it appears that the consumption of fuel is $\frac{1}{3}$ more than it should be for equal effects. What is shown to be the losses of this concern, may be repeated, ad infinitum, in many of the large establishments of the country using steam power.

ON THE BEST METHOD OF RAPIDLY CONSTRUCTING LONG TUNNELS.

By G. BRIDEL.

From Selected Papers of the Institution of Civil Engineers.

THE facts from which the author draws his deductions relate principally to the Mont Cenis, St. Gothard, and Arlberg tunnels, a comparison being made between the modes of tunnelling adopted, divisible into two systems, viz., first, that of driving the advance-heading near the level of the roof of the intended tunnel; and secondly, where it is driven at the invert-level. The comparative merits of these two methods are reviewed, as regards speed of execution, suitability under various conditions, and economy.

In the St. Gothard tunnel, where the first-mentioned or "crown-heading" (Belgian) system was adopted, the piercing was effected in much less time than in the case of the Mont Cenis, where the advance-heading was driven at the low level, or on what may be termed the "base-heading" (English) system. This advantage, however, was neutralized by the fact, that after this stage had been attained the completion of the Mont Cenis tunnel was effected in nine months, as compared with twenty-two months in case of the St. Gothard.

The author attributes this discrepancy to the facilities afforded by the "base-heading" system, in the subsequent excavation and transport, and the non-necessity for the frequent shifting of the temporary running-road and the air-conduits.

At the Arlberg tunnel, commenced about two years ago, the base-heading system has been adopted, with the result that although the rate of advance of the heading is 50 per cent. more than that attained at the St. Gothard, the completion of the tunnel section follows as close upon the heading as was the case at Mont Cenis.

The mode of procedure in this instance was to excavate a series of vertical shafts (about three chains apart) from the roof of the heading upwards, until reaching the level of the crown of the intended arch; the upper portion of these shafts was then widened out, the excavation being shot, as through a funnel, into the wagons on the base-heading track.

On the 31st December, 1881, the east heading of this tunnel had been driven for a distance of 2,031 yards, and the length of the finished tunnel was 1,170 yards, or 861 yards in arrear of the former. In July, 1882, the lengths of completed tunnel and heading were 2,544, and 3,288 yards respectively, the difference being 744 yards, or 117 yards less than six months previously. At the west end the amount of arrear was slightly greater, due to the bad character of the ground traversed. This difference, however, is being lessened, and the base-heading system is considered to have been thoroughly successful.

A diagram showing the order in which the various portions of the tunnel area are excavated is given. The ventilation was effected by a special set of air-pipes (independent of their supplying the boring machinery) varying from 1 foot $3\frac{3}{4}$ inches to 1 foot $7\frac{3}{4}$ inches in diameter in the finished portion of the tunnel, and reduced to 1 foot where the work was proceeding. The air was delivered at a pressure of 3 lbs. per square inch.

The base-heading system was adopted at the Mont Cenis, and at first worked in the same manner as the above-described (Arlberg); but afterwards the excavation from above the advance-heading was worked out in two cores, from the face instead of by shafts. This method necessitated the use of very strong timbering for the base heading (advance), but as the fissured nature of the rock would have made this requisite under any circumstances, no additional expense was entailed. Mention is made of the Laveno tunnel, where continuous base and crown headings, with occasional communicating shafts, were pierced by mechanical boring throughout the length of the tunnel, the excavation being re-

moved through the lower heading. The tunnel was 3,210 yards long, and was constructed in sixteen and a half months. This last method is recommended where the motive power sufficient for actuating the additional boring machinery is obtainable.

The crown-heading system is then considered. The adoption of this system at the St. Gothard was principally due to the contractor, who, having his choice, preferred working on a system to which he had been accustomed. It was also hoped that with a crown-heading a better ventilation for the workmen would be procurable than had been the case in the Mont Cenis tunnel.

The advance-heading is followed by the removal of the excavation on each side, and as soon as springing-level is reached, the arch is constructed, and progressively underpinned with timber, permitting the erection of the side walls one at a time. The temporary way is first laid in the crown-heading, and as the various tiers of excavation below this are removed, the difference of level between each tier is surmounted by inclined planes of timber framing. Hydraulic elevators were introduced, but had to be abandoned on account of their being affected by the gases from the tunnel. A diagram shows the order in which the various cores of excavation are removed, and another compares the length of tunnelling under construction (Chantiers), at one and the same time, in the St. Gothard and the Arlberg tunnels. The distance from the completed portion to the heading of advance (crown-heading system) is in the former instance 3,007 yards, whereas in the Arlberg tunnel it is reduced to 1,258 yards.

A third diagram shows the progress of the excavation of the headings and the various cores, and of the masonry from end to end of the St. Gothard tunnel.

From this it is seen that the progress of the arch is irregular, and is accounted for by the desire on the part of the contractor to avoid expense, sought to be attained by shifting as seldom as possible the inclined planes connecting the tiers of excavation, stretching from the face of the advance heading to the formation-level at the finished tunnel. The author, after estimating the lengths occupied by the various processes of excavation, of blasting, and the inclined planes, &c., concludes that the normal length of the tunnel under construction (Chantiers) at one and the same time, with this system, cannot be less than 2,586 yards, and that the crown-heading is not suitable for cases where mechanical boring is resorted to and expedition of importance.

The most suitable system to be adopted in passing through ground exerting great pressure is considered, whether by constructing the arch first and then the side walls, or the reverse. When the arch is constructed first, allowances should be made for its settlement, as however carefully it may be underpinned, in ground of this character subsidence and an inward movement of the springing is almost certain to ensue as soon as the whole excavation of the tunnel section has been removed. An instance is mentioned where the allowance for settlement was as much as 3 feet 3 inches in the "windy stretch" of the St. Gothard, and of the difficulties encountered and distortions of the arching which occurred in the Foggia-Naples tunnel, where the ground was of a plastic nature; the opinion being that under such circumstances the Belgian method of constructing the arch prior to the side walls should not be attempted.

The cost of excavation to the full section of a tunnel constructed by means of the crown-heading, where the boring is done entirely by hand labor, is 10 per cent. less than the same work where the base-heading is adopted; but when mechanical boring is resorted to, the saving in this item is reduced to 1.82 per cent. The cost of transport, however, is less with the base-heading system, and, as before mentioned, it is not necessary to shift the temporary track and the air-conduits, as is so frequently requisite in the crown-heading system; also the drainage is much better under control. A diagram shows the number of changes of the temporary track (including turnouts and lie-byes), air-pipes, &c., on 1 kilometer of the St. Gothard tunnel during the term of construction (thirty-nine months). The percentage of the total number of men employed in connection with these latter items is 10 per cent., and this expense is reduced to

comparatively nil where the base-heading system is adopted.

In the St. Gothard tunnel, up to the time of the junction of the north and south headings, the ventilation was very imperfect; air was supplied to the length under progress by piercing the pipes conveying air at a pressure of 90 lbs. (six atmospheres) to the boring machinery, but the motive power was insufficient to maintain a sufficient supply at that pressure, so that neither proper ventilation nor supply to the boring apparatus was attained.

The contractor for the Arlberg tunnel was paid

	£.	s.	d.	
At the rate of....	79	17	7	per lineal yd.
Interest on plant supplied by the company.....	17	5	0	„ „
	£97	2	7	

The contractor of the St. Gothard Tunnel was paid

	£	s.	d.	
At the rate of....	133	4	3	per lineal yd.

The rock formation of the St. Gothard was harder than at the Arlberg.

In conclusion, the author is of opinion that for tunnels required to be executed with rapidity, the method of base-heading is preferable to crown-heading.

REPORTS OF ENGINEERING SOCIETIES.

American Society of Civil Engineers.—January 2, 1884.—The Society met at 8 P. M., Vice-President Wm. H. Paine in the chair; John Bogart, Secretary.

The following candidates were elected members:

William Hammond Hall, Sacramento, Cal.; Charles Warren Hunt, New York City; Stillman W. Robinson, Columbus, Ohio; transferred from junior to member, Frederick Brooks, Boston, Mass; elected junior member, Edward E. Magovern, Hoboken, N. J.

The death, on December 27th, 1883, was announced, of General A. A. Humphreys, U.S.A., Honorary Member of the Society. Arrangements for the annual meeting of the Society on January 16th and 17th were read.

A paper by Mr. A. V. Abbott, on "Some Improvements in Testing Machines," was read by the author, and illustrated by a stereopticon. A 200,000 pound testing machine was first described, its general construction providing for weighing the forces applied by means of platforms and levers somewhat similar to those used in ordinary scale work, with special arrangements to reduce friction. To secure the direction of the pressure upon the test pieces in the axis of the machine, both ends of the piece are connected with segments of spheres moving freely in spherical sockets, which take the proper position upon the first application of the stress. Arrangements are also made by means of wedges to grip and hold uniformly the ends of the test pieces. The machine is arranged to test in tension compression, for transverse stress, for shearing, bulging and torsion. In the machine illustrated, the action of applying stress is automatic, and at the same time the same power gives an autographic record of the stress applied, and of any variations which may occur during the continuance of the stress, and with an instantaneous autographic record of the result at the conclusion of the test. The stresses are applied by means of weights which slide upon two parallel lever beams, the one registering up to 10,000 pounds and the other up to 200,000. By means of a remarkably ingenious electrical attachment, connected with clockwork, the movement of these weights is continuous and automatic, and the registering apparatus is also controlled by the same electric current. It is impossible in this abstract, and without the aid of a diagram, to fairly describe the details of these movements, but they seem to be very complete and accurate. Diagrams automatically made by the machine were exhibited and described.

A number of broken pieces of steel were exhibited, and also specimens of woods which had been tested in various ways. Machines of smaller powers were also described, and a number of briquettes of cement were broken upon a small automatic machine which was exhibited.

The discussion of the paper was postponed to a subsequent meeting.

At the annual election, held on the 16th of January, the following officers were elected:

For President, Don. J. Whittemore; Vice-Presidents, Wm. H. Paine, Joseph P. Davis; Secretary and Librarian, John Bogart; Treasurer, James R. Croes; Board of Directors, Geo. S. Greene, William Metcalf, Theodore Cooper, Fred. Graff, Wm. R. Hutton.

ENGINEERING NOTES.

The trusses of the old part of the roof of the Basilica of St. Paul, at Rome, were framed in 816, and were sound and good in 1814, 1,000 years later. These trusses are of fir. The timber work of the external domes of the Church of St. Mark, at Venice, is more than 840 years old, and is still in a good state. Sound logs are dug out of bogs where they have lain for an indefinite period.

A trial has been made by the Consolidated Electric Company with an accumulator used to light up a carriage of Mr. A. de Rothschilds. A test journey from Halton to Tring Station and back was made again on Sunday evening. The light is under the command of the occupant of the carriage, who can light or extinguish either of the lamps. An incandescent light is placed in each of the ordinary outside

carriage lamps, and one arranged with a small bracket and globe inside. The current is applied from five cells, containing six metal plates in each, which can be recharged without disturbing the arrangements by simply connecting two wires. The whole, being contained in a small mahogany case, weighing a little over 1 cwt., can be easily removed from the carriage, if necessary.

EXPERIMENTS have been made at J. W. Pease & Co.'s limestone quarries, Weardale, in drilling the rock with Cranston's steam-power machines in the blue mountain limestone. The trials have been regularly and systematically carried on during the past twelve months, and a correct statement of the work accomplished has been kept the whole of the time, in which many hundred feet of holes have been put down from 4ft. to 18ft. deep each by 2in. to 3in. diameter, some of the holes having been drilled 5ft. deep in one hour with a 2in. gauge drill. One of the holes 18ft. deep, by an excellent system of blasting, is estimated to have removed 3,000 tons of rock, using 4½ barrels of powder; some 9ft. holes, being 2¼in. diameter at the bottom of hole, have displaced over 400 tons with a little less than ¼ barrel of powder. These quarries are very extensive, being close upon 500 yards long, with a fore breast of splendid rock about 50ft. deep. The average output at the present is about 2,000 tons per week. The rock is principally used in the blast furnaces of Cleveland. A line of railway, 4ft. 8½in. gauge, has been specially laid down from one end to the other on the quarry top, so that a portable boiler runs along it and supplies steam to the rock drills at any desired part.

KERITE TELEGRAPH CABLE.—Kerite is the invention of an American manufacturer, Mr. A. G. Day, who was impelled by the increasing cost of india-rubber to seek a substitute for it as an insulating material for electric wires. The invention is patent, and the substances of which kerite is composed are not made public, but it is known that it is composed of various bodies. It may be combined with india-rubber, sulphur, and oxides of metals in the usual manner; renders the india-rubber more durable, while reducing the cost, and is applicable to the whole class of goods into the manufacture of which caoutchouc enters. At Mr. Day's factory at Seymour, Conn., the whole process of the manufacture of cable is carried on, except that of making the wire. The ingredients of the kerite are thoroughly mixed, put into boilers, and allowed to stand until ready for use. When hot the composition is of about the consistency of thick treacle; it is run into cakes, which, when cool, are kept separated by a thin layer of soapstone, in order to facilitate handling. Pure Para gum, cleansed by a process of Mr. Day's invention, is then thoroughly mixed with the kerite by the usual grinding operation, and the whole carefully strained. It is afterwards cut into strips about an inch square, and fed into a machine, which covers it on to the wire as the latter passes through. The wire is then coiled in layers in large pans, fine soapstone dust being used to prevent adhesion, and is vulcanized. The coils are afterwards rewound upon "testing reels," and submerged in water for forty-eight hours. The wire is most carefully tested while in the bath, and the process is then complete. Wire for single lines is wound and despatched at this point,, while that for cables is wound up for the cable-making machines. Submarine cables have a coating of prepared tape over each strand, they are then surrounded with an envelope of jute fiber, and, lastly, enclosed in an armor of the best "B. B." galvanized iron wire.

TOWAGE BY ENDLESS CHAINS.—An interesting experiment in the towage of vessels by means of endless chains has been made on the Rhone by M. Dupuy de Lome. That river is troubled with rapid currents and stony shallows, hence navigation is troublesome on it, and it has not, therefore, been utilized to its utmost. The state of the bed is improving every day, however, owing to the dredging and other engineering operations now carried out; but after these are executed the Rhône will still remain too swift at several parts for ordinary sailing. Towage by means of ordinary chains is also open to several objections which do not hold in the case of towage by endless chains worked in the following manner: A tug boat is provided fore and aft on each side with an endless chain, sufficiently heavy, and plunging into the water so as to rest on the bottom for a space, the part on board being sustained by pulleys. These pulleys being turned by hand or by an engine, the chain moves with them, propelling the boat against the stream. The chain on each side is actuated by a separate motor, the craft is steered by making one chain move faster or slower than the other. The chains are disposed in such a way that for the greatest depths, the weights resting on the bottom produce an adhesion to the latter still greater than the drag of the tugs and its convoy. The experiment of M. Dupuy de Lome was made at the instance of the Minister of Marine, M. Zédé, director of naval constructions in France, and took place at the Port-de-Bouc. The tug was a vessel 33 meters long by 7.50 meters wide, and 2.10 meters deep. The two strong chains employed weighed 46 kilogrammes per running meter. Each was worked by an engine of 15 horse power, and the two machines were completely independent. but the valves and starting gear were under the control of one man. The trials showed that the barge could be properly steered and propelled in this manner in varying depths. The proper length of chain for the depth was regulated by increasing or diminishing the distance between the front and rear pulleys. The depth varied from 1 to 6½ meters, and provision was made accordingly. The coefficient of friction of the chain on the bottom was found to vary with the nature of the bottom from 80 to 120 per cent. of the weight of the chain in air. It was thus possible to calculate what the current should be in order that the chains should not slip on the bottom. Currents of 3 meters per second were successfully encountered and overcome, and the vessel could be properly manipulated in these rapids with a safety unknown to other methods of navigation. The new plan of M. Dupuy de Lome is in fact highly interesting

and ingenious, and may be useful in mounting rapid rivers in many other countries.

IRON AND STEEL NOTES.

DESPITE the fact that the steel trade has not of late been advancing with as rapid strides as could be desired, the promotion of extension of works and the establishment of new works continue. The Glasgow Iron Company has acquired 15 acres of ground at Wishaw, near its ironworks, for the purpose of erecting a steelworks. The contracts have been placed for the machinery and buildings, part of the machinery to be supplied by an English house, part by the Vulcan Foundry, Glasgow, and the roofing of the buildings by Messrs. P. and W. M'Lellan, of Glasgow. It may be stated here that the last-named firm have secured the contract to supply the ironwork to be used in the erection of the Glasgow Municipal Buildings.

THE iron trade of Belgium is in an exceptionally depressed state for want of orders; and ironmasters have been casting about for something just to keep their works open during the winter. They observe that iron sleepers are largely used in Germany, where they are ordered in lots of 20,000 and 30,000 tons at a time, whereas in Belgium the trials made were not considered to give good results. They attribute this circumstance to the attempt to make iron permanent way for the same price as one with timber sleepers. The economy due to the use of the iron results from the greater duration and the reduction in labor for renewals, while the old iron is always worth something for working up again. M. Sadoine, of the Cockerill Works, convened a meeting of ironmasters at the Grand Hotel, Brussels, when it was agreed to petition the Minister of Public Works to institute on the State railway a fresh series of experiments with iron sleepers, and to intrust a trial order of 1,500 to 2,000 tons to each of the principal ironworks, one-third of the price to be spread over five years, at the rate of interest to be agreed upon. M. Victor Gilliaux, President of the Association de Maitres de Forges de Charleroi, undertook to hand the petition to the Minister. The ironmasters rely upon the Minister's well-known solicitude for the welfare of the working class to give this proposition a favorable consideration.

RAILWAY NOTES.

THE Railway Commission appointed to investigate the management of the passenger traffic of the Queensland railways have recommended that a board be appointed to supervise the management and construction of railways, and to see that safety, convenience, and the interests of the public are duly regarded. The commission have also recommended that appointments to the railway service should be vested in a board. An inquiry into the management of the freight traffic is strongly advised.

RAILWAY MATTERS.—The largest locomotive ever built in America is now being made in Sacramento by the Central Pacific Railroad. The engine and tender will weigh 105 tons, and will be 65ft. 5in. long.

TWO engineers of the Paris, Lyons and Mediterranean Railway have made the discovery that the rails on the line between Marseilles and Rognac have become strongly magnetized by the friction exerted by the passing trains. The magnetization is not appreciable until the fish-plates are removed and leaves the rails soon after they are taken up.

THE railway from Liege to Maestricht, says a Belgian paper, has obtained permission to put on its track, between Liege and Vise, small trains, made up of cars, of the tramway pattern. These trains stop between stations, and thus are a great convenience for the small villages along the route. They are much appreciated, and, not the least striking fact, the railway company adopted this system in order to prevent the establishment of any competing tramway line. This, says the *Railroad Gazette*, is an idea that perhaps might be advantageously adopted by some lines in our own country.

IN a paper on "Compressed Air Locomotives for Mines," published in the "Génie Civil," M. Edmond Boca claims for them the following advantages over chain haulage: (1) Greater simplicity of installation, owing to the suppression of pulleys, rollers and guides. (2) The dispensing of a double line of way and a special road for workmen. (3) Their capability of serving several galleries, of being easily transported from one working place to another, and of avoiding the risk of stoppage. (4) The facility of apportioning the power to the work, while the driver always has his engine under command.

"DURING a recent visit to Darjeeling," writes a *Times* correspondent, "I was much impressed by the great advance visible in the prosperity of the station and district since they were brought into connection with the Indian railway system two years ago. Within a few days' march of the terminus of the mountain railway lines is the richest and most populous part of Tibet, inhabited not like the trans-frontier districts of the Punjab, by Mahomedan cut-throats, but by a peaceable and trade-loving people. At present the bulk of the trade between India and Tibet is obliged to follow a most circuitous route, through Nepaul, and it is charged duty on entering and leaving that country. Notwithstanding these difficulties, the trade continues to increase. The direct route lies unquestionably through Darjeeling, and goods can now be conveyed by rail to within a week's journey from the frontier. The removal of the existing restrictions would open new and enormous markets for tea, indigo, tobacco, and other Indian products, as well as for hardware and the cotton goods of Manchester. This market would supply us in return with inexhaustible quantities of the finest wool, and with musk, borax, &c." Cheap railway extension works would, it would appear, promise a good future return.

THE question of the junction of the network of the Austro-Turkish railways now occupies the attention of the Ministry. Austria raises objections to the point of junction chosen by Turkey, while the admission into the protocol of the invidious phrase that the junction should be made "par le tracé le plus convenable" places the Porte in a dilemma out of which it is difficult to escape. The shortest, cheapest, and most direct "trace" is from Vranje to Uskup, and this is therefore "le trace le plus convenable," adopted in principle in the protocol signed by the Turkish Minister, who is now instructed to oppose it.

EXPERIMENTS have of late been carried out on various Prussian railways with a view of deciding the relative merits of petroleum torches and of those made from pitch or resin. The results arrived at indicate that, although the former give a clear light, and are especially convenient in some respects, they are more dependent upon the weather, and are not well adapted for casting light for a little distance around where they are placed. While of service in repairs connected with the maintenance of the permanent way, it is considered that in accidents pitch or resin torches are preferable. With a view of these latter being always available upon an emergency, orders have been issued for a supply being kept at all stations, signal cabins, &c., and every luggage van and tender will carry several of them.

THERE is a fiction that engines on the Metropolitan railway are not as other engines, and that they never leave the rails. Board of Trade reports tend to destroy this fiction, and to show that rigid wheel base and sharp curves are as evidently the cause of derailment on the subterranean as on other lines. Colonel Yollard has written a report on the accident which occurred on the 3rd October, between Farringdon Street and Aldersgate Street, when the four leading bogie wheels of a Metropolitan District engine mounted the rails, and ran for a distance of about thirty-eight yards off the rails before the train was stopped. No damage was done to the engine or carriages in the train or to the permanent way, and no complaints have been received from any of the passengers in the train. A precisely similar accident occurred on the 10th May last, at the same spot, to a Metropolitan District Railway Company's passenger train, and it was then recommended that the Metropolitan Railway Company should insert check-rails on all their lines on curves having a radius of ten chains or less, and not permit such curved lines to be laid tight to gauge. Since this second accident in the same place in one year, check rails have been put in.

ORDNANCE AND NAVAL.

THE third ironclad, the Help in Need, corvette, built for the Chinese Government, has been launched at Stettin. She has a waterline length of 72 meters, a breadth of 10.5 meters, and a depth of 7.20 meters, while her greatest draught of water when fully equipped, will be 4.8 meters. The two bi-cylindrical compound engines, each driving a screw, have together an indicated horse power of 2,800, and ought to give the vessel a speed of fifteen knots an hour. The displacement of the finished ship will be 2,355 tons. Her armament will comprise two turret Krupp cannon of 21 centimeters, another Krupp gun of 15 centimeters, four torpedo guns, and six Hotchkiss cannon. The vessel will be manned by a crew of 180 officers and men.

AT the official trial of the little twin steamships Jeanne and Louise, on the Mersey, a speed of 8 knots was obtained with a load of 18 tons on a draft of 2 feet 6 inches. The vessel, which is built of steel, is 60 feet long, 12 feet beam, and 4 feet 3 inches deep, with raised forecastle, and deck-house amidships. She is fitted with two single-crank tandem compound engines, having cylinders 5 inches and 10 inches diameter, by 8 inch stroke, fitted with a wrought iron surface condenser, and a separate engine for air and circulating pumps. The boiler is of Cochran's patent multitubular type, 4 feet diameter by 8 feet 6 inches high, and is made of mild steel throughout. The vessel and machinery were built for service on the Gaboon River, on the West Coast of Africa.

THE 3,660 shipping disasters which occurred off the coasts of the United Kingdom during the year 1881-82, comprised 4,367 vessels. Unfortunately, the number of ships is larger than the total of the previous year by 70; it exceeds the casualties reported, because in cases of collisions two or more ships are necessarily involved in one casualty. Thus, 686 were collisions, and 2,974 were wrecks and casualties other than collisions; 523 of these latter disasters were wrecks, &c., resulting in total loss; 719 were casualties resulting in serious damage, and 1,729 were minor accidents. In the previous year, 1880-81, the wrecks and casualties other than collisions on and near our coasts, numbered 2,862, or 112 less than the number reported during the year 1881-82. We observe that out of the 2,974 casualties, other than collisions, 2,623 occurred to vessels belonging to this country and its dependencies, and 351 happened to foreign ships. Of these 2,623 British vessels, 1,663 were employed in our own coasting trade, 720 in the—oversea—foreign and home trade, and 240 as fishing vessels. There were 8 casualties to ships belonging to foreign countries and States employed in the British coasting trade, and 275 to foreign vessels which, although not engaged in our coasting trade, were bound to or from British ports; while there were 68 casualties to foreign ships which were not trading to or from the United Kingdom. Excluding collisions, the localities of the wrecks are thus given: East Coast of England, 809; South Coast, 586; West Coasts of England and Scotland, and East Coast of Ireland, 1,046; North Coast of Scotland, 99; East Coast of Scotland, 161; other parts of the coast, 273; total, 2,974.

BOOK NOTICES.

PUBLICATIONS RECEIVED.

CIRCULARS of information of the Bureau of Education, Nos. 2 and 3. Washington: Government Printing Office.

Report on the Waters of the Hudson River. By C. F. Chandler, Ph. D. Albany: West, Parsons & Co.

Professional Papers of the Corps of Royal Engineers, containing:

Provisional Fortification, Errors in Graduated Arcs, Lord Lake's Campaigns, 1804–6; Blasting Operations, Demolition of Barque Caroline Z., Bridges of the Kabul River, Railway Curves, Railways for Military Communication in the Field, Tables of Service Ordnance.

Professional Papers of the Signal Service:

No. VIII.—Motion of Fluids and Solids on the Earth's Surface. By Professor William Ferrel.

No. IX.—The Geographical Distribution of Rainfall in the United States. By H. H. C. Dunwoody, First Lieut. 4th Artillery.

No. XI.—Meteorological and Physical Observations on the East Coast of British America. By Orray Taft Sherman.

No. XII.—Popular Essays on the Movements of the Atmosphere. By. Professor William Ferrel.

A TEXT-BOOK ON PHYSICS. By Henry Kiddle, A. M. New York: Wm. Wood & Co.

This is an abstract of Ganót's Physics, adapted for the use of academies and high schools.

It has been arranged by a skillful instructor, and the illustrations are made to appear with all of the original excellence which made the original edition so attractive.

A TREATISE ON THE MOTION OF VORTEX RINGS. By J. J. Thomson, M. A. London: Macmillan & Co.

This essay earned the Adams prize at Cambridge University in 1882.

The discussion involves mathematical analysis of a difficult order, and will prove profitable reading only to students who are well advanced in pure mathematics.

The literature of this line of research is not extensive, but the subject has of late excited a deep interest among physicists everywhere.

NOTES ON GUNPOWDER AND GUNCOTTON. By Lieut.-Col. W. H. Wardell, R. A.

This is prepared for the use of the gentlemen cadets of the Royal Military Academy, Woolwich.

In separate chapters the writer treats of Constitution and Action of Explosive Substances, Ingredients and Properties of Gunpowder, Fired Gunpowder, Preparation and Purification of the Ingredients of Gunpowder, Manufacture of Gunpowder, Examination and Proof of Gunpower, Guncotton, its Chemical and Physical Properties; Manufacture of Guncotton at Waltham Abbey.

A SUMMARY OF TACTICS. By H. F. Morgan. London: Marcus Ward & Co.

This is a companion to "A Summary of Military Law," compiled by the same writer. It is arranged in the question and answer style, and includes the following topics:

Characteristics of the Three Arms, Ground in Relation to Tactics, Space and Time Required, Marches, Advanced Guards, Outposts, Reconnoitring, Employment of Infantry, Employment of Cavalry, Employment of Artillery, The Three Arms Combined, Attack and Defense, Rearguards, Defiles, Rivers, Woods, Villages, Convoys, Inferences drawn from Tactics in late Wars. A few very neat diagrams illustrate the text.

THE TOPOGRAPHER: HIS INSTRUMENTS AND METHODS. By LEWIS M. HAUPT, A. M., C. E. New York, J. M. Stoddard. Price $4.00.

A book which treats of the improved methods of topographical surveying has long been needed. Learners have been obliged to seek for such instruction in scientific journals and to search through many scattered articles to acquire a fair summary of the best modern practice.

We find this manual of Prof. Haupt. all that seems necessary for a complere treatise.

The improved instruments are described and their adjustments and use explained.

Mapping, modeling, and recording notes are fully described.

The illustrations are numerous and pretty good. The work is a valuable supplement to the common treatises on surveying.

KNIGHT'S NEW AMERICAN MECHANICAL DICTIONARY. Section 4. Boston, Houghton, Mifflin & Co.

This is the concluding part of the new edition. It concludes articles from "Printing Press" through to "Zoogyroscopic."

The former edition was an excellent reference book, indispensable to the mechanical engineer. The present edition is an improvement inasmuch as it contains descriptions of later devices and a larger proportion of good illustrations.

MISCELLANEOUS.

A course of lectures on "Meteorology," by Mr. W Marriott, F. R. M. S., was delivered at Westminster. This lecture was devoted to the consideration of atmospheric pressure. Having referred to Torricelli's experiment, proving that a column of water 32ft., or of mercury 30in., is in equilibrium with the pressure of the atmosphere, the lecturer explained the construction of the barometer, and described the Fortin, Kew siphon, aneroid, and other forms of this instrument. As the pressure decreased with altitude, it was shown how the barometer could be used for the measurements of heights. It was pointed out that there is a diurnal range of atmospheric pressure, which consists of two minima about 4 A. M. and 4 P. M., and two maxima at about 10 A. M. and 10 P. M. This phenomenon is most remarked in the tropics. Having referred to the connection existing between the changes of atmospheric pressure and the flow of underground water, and also colliery explosions, the lecturer explained the construction of isobaric charts, and by the aid of such charts showed

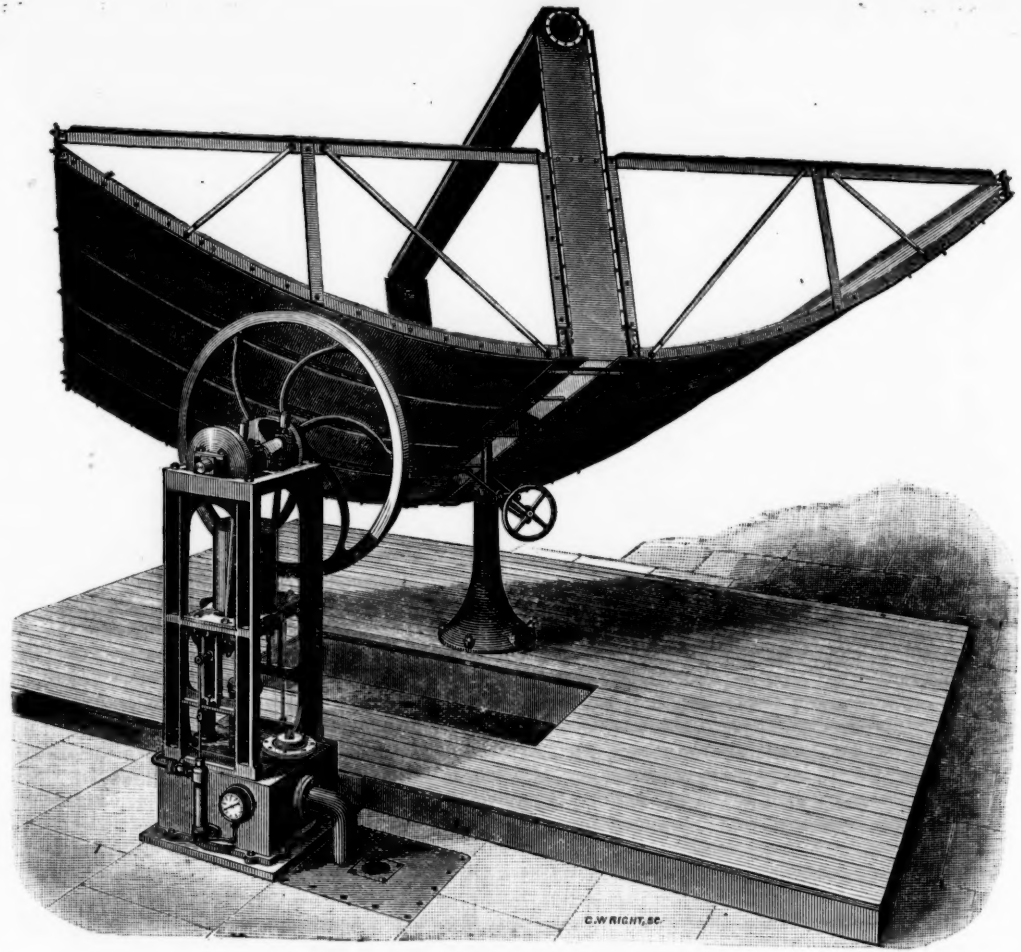
the distribution of pressure over the globe during the months of January and July.

CONVERSION OF LIGHT INTO ELECTRICITY.—The conversion of electricity into light is now a fact of every-day utility, but the reverse process has been very slow of accomplishment. It has, however, been effected by Herr Sauer. whose sunlight battery has been described in the *Electrotechnische Zeitschrift*. The chemical rays furnish the power, and the battery will only act in sunlight. It consists of a glass vessel, containing a solution of fifteen parts of table salt and seven parts of sulphate of copper, in 106 parts of water. In this is placed a porous cell containing mercury. One electrode is made of platinum, and the other of sulphide of silver, and both are connected with a galvanometer. When not in use the whole is enclosed in a box. When in use, the platinum electrode is immersed in the mercury, and the other in the salt solution; the battery is placed in the sunlight, and the galvanometer needle is then found to be deflected, the sulphide of silver being the negative pole. If the sun is clouded, or any other change in the intensity of the light occurs, it is indicated by the needle. The exact effect produced by the light rays does not as yet appear very clear, but their presence distinctly produces electrical action, and their absence suspends it.

A NEW COMPASS.—M. Mascart, the well-known electrician, has devised a new compass which finds the magnetic meridian by the well-known experiment of moving a coil of wire across the lines of magnetic force of the earth and inducing a current in them. M. Mascart employs an azimuth circle on which is mounted a ring movable round a horizontal axis. The angle made by the ring with the horizon is measured by a vertical circle. A coil of 0.21 metres in diameter is carried by the ring and can turn round an axis perpendicular to that of the ring. The size of the apparatus is not greater than an inclination compass. It acts on the principle that when the axis of rotation of the coil is in the magnetic meridian the induced currents in the ring when rotated will be nil. A sensitive galvanoscope is employed to show the induction currents. In using the apparatus, a series of trials show that the axis of the ring is perpendicular to the magnetic meridian. A second series place the axis of rotation of the coil in the line of the inclination needle. The observation, with checks, occupies half an hour which is less time than is necessary to find the inclination by a magnetic needle. From observations made at the Observatory of the Parc Saint Maur, by M. Mourceaux, the new compass seems to be as correct as the inclination compass.

AT a recent meeting of the Royal Society, Edinburgh, Sir William Thomson read two papers on gyrostatics and on oscillations and waves in an adynamic gyrostatic system. The papers were in great part experimental illustrations of the theorems regarding gyrostatic stability which are laid down in Thomson and Tait's "Natural Philosophy." It was thus demonstrated to the eye that a system when under gyrostatic domination is stable in positions for which, statically considered, the system is unstable as regards an even number of degrees of freedom; so that, to take a particular case, a gyrostat which is unstable, because statistically unstable as regards one mode, is rendered stable by making it statically unstable as regards two modes. Hence also an ordinary spinning top is stable because it is statically unstable in two of its degrees of freedom. The curious behavior of a gyrostat resting horizontally on gimbals with its axis of rotation vertical was also shown, viz., its instability as soon as the framework on which it rested was moved in the opposite rotational sense to the spin of the gyrostat. The author then proceeded to point out that all phenomena of elasticity which are ordinarily treated by assuming forces of attraction or repulsion between parts or stresses through connections, can be as readily explained by the assumption of connecting links subject only to gyrostatic domination. The gyrostatic hypothesis led to other consequences which the ordinary dynamic assumption did not involve; but it had not been found as yet that elasticity had properties corresponding to these.

THE CHINESE FOOT RULE.—A writer in the *North China Herald* gives some curious information respecting the foot measure in China. At present it varies largely in different parts of the country, and according to different trades; thus the foot of the carpenter's rule at Ningpo is less than ten, while that of the junk builders at Shanghai is nearly sixteen inches. But a medium value of twelve inches is not uncommon. The standard foot of the Imperial Board of Works at Peking is twelve and a half inches. A copper foot measure, dated A. D. 81, is still preserved, and is nine and a half inches in length. The width is one inch. The small copper coins, commonly called *cash*, were made of such a size, sometimes, as just to cover an inch on the foot rule. In the course of two centuries it was found that the foot had increased half an inch, and a difference in the dimensions of musical instruments resulted. Want of harmony was the consequence, and accordingly in A.D. 247 a new measure, exactly nine inches in length was made the standard. Among the means employed for comparing the old and new foot are mentioned the gnomon of official sun-dials, and the length of certain jade tubes used according to old regulations as standards. One of these latter was so adjusted that an inch in breadth was equal to the breadth of ten millet seeds. A hundred millet seeds or ten inches, was the foot. The Chinese foot is really based on the human hand, as is the European foot upon the foot. It strikes the Chinese as very incongruous when they hear that we measure cloth, woodwork, masonry, &c., which they regard as especially matters for the hand, by the foot. Of the jade tubes above mentioned there were twelve, and these formed the basis for the measurement of liquids and solids four thousand years ago. They are mentioned in the oldest Chinese documents with the astrolabe, the cycle of sixty years, and several of the oldest constellations. It is likely that they will be found to be an importation from Babylon, and in that case the Chinese foot is based on a Babylonian measure of a span, and should be nine inches in length.



Ericsson's Sun Motor, erected in New York, 1883.